INSTRUCTIONS

JEM-2000FX

ELECTRON MICROSCOPE

No. IEM2000FX-2
(EM133021)

Serving Advanced Technology

JEOL 日本電子

3511124

To The User:

The descriptions in this manual may not be identical in some respects with those of the instrument delivered owing to specification differences or improvements that have been made. Before making use of the manual, please verify the specifications against those when the order for the instrument was placed.

Kindly note that while the instrument can be used in combination with various attachments to serve a number of purposes, this special feature of the instrument is only briefly described in this manual, which chiefly covers basic operations.

CONTENTS

[FLOWCHARTS]

[ATTACHMENTS]

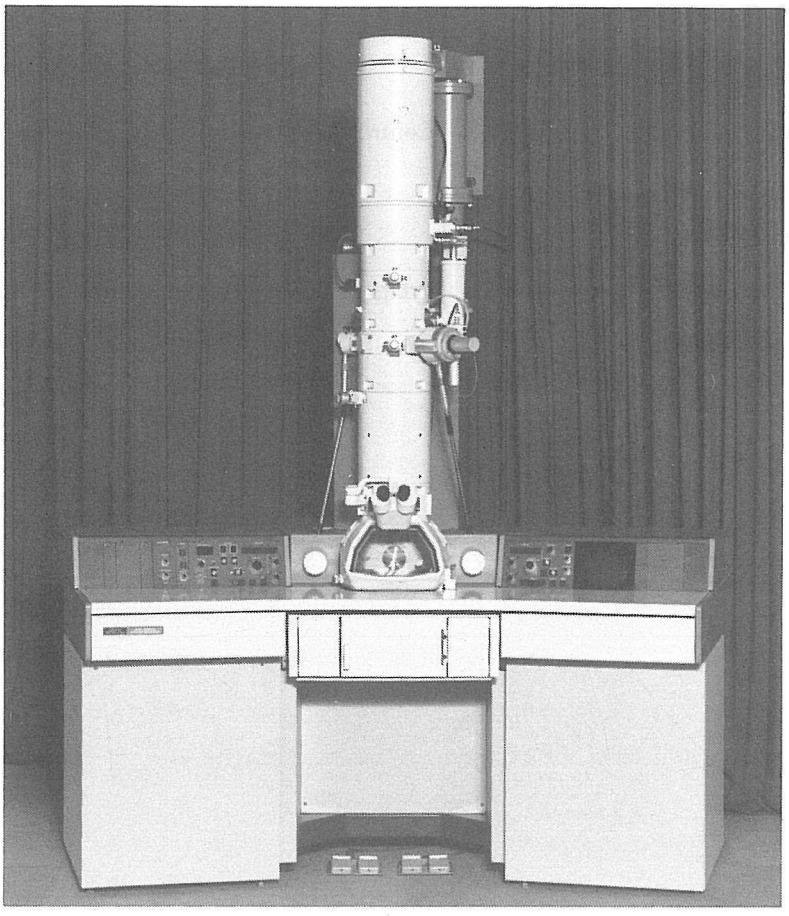
1. GENERAL

1. GENERAL

1.1 Feature

With a view to obtaining accurate information from the specimen, special attention has been paid to improvement of the specimen environment in the JEM-2000FX. The dry pumping system and minimum electron dosage system are available to achieve this purpose. It goes without saying that various new design cocepts are incorporated in the optical system. The advanced imaging-lens system minimizes image rotation due to magnification change, curtailment of field of view, and off-axial aberration.

Through keyboard operation, the optical system can be freely controlled and a specific condition can be stored in the memory and read out. Operating condition data can also be displayed on CRT and part of it printed on film. Write-in of user's comments and storing them in the memory are also possible through keyboard operation.



JEM-2000FX (with attachments)

1.2 Main attachments

The instruction manuals of some attachments which are commonly used are appended to the end of this manual regardless of whether they are used in combination with your JEM-2000FX.

Type	Name	Purpose
AD	High resolution diffraction stage	
ASEA	Energy analyzer	Measures the energy spectrum of transmitted electrons.
ASID	Scanning image observation device	For secondary and transmitted electron scanning image observtion.
BS	Beam stopper	Intercepts the electron beam at the desired point in the microscope screen center.
CP	Air compressor	Controls the pneumatic valves.
DHM	Hour meter	
DSC	Desiccator	For film desiccation.
EDS	Energy dispersive X-ray spectrometer	
FLC	Free lens control unit	Controls lens currents freely.
LKS	LaB_6 filament	
MPA	Micro-particle analyzer	
PRT	Printer	Prints out all the information displayed on the CRT.
SCH	Specimen cooling holder	
SEH	Specimen elongating holder	
SHH	Specimen heating holder	
SRH	Specimen rotating holder	
STH	Specimen tilting holder	

2. SPECIFICATIONS

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This chapter covers the specifications relative to setting up and operating the microscope when the AHP high resolution pole piece is used.

2.1 Performance

- Accelerating voltage: 80, 100, 120, 160, 200 kV.
- Magnification (digital display, film printout)
  - Standard magnification mode: 1,000X to 850,000X in 30 steps.
  - Selected area magnification mode: 3,400X to 410,000X in 22 steps.
  - Low magnification mode (LOW MAG): 50X to 1,000X in 14 steps.
- Electron diffraction camera length (digital display, film printout)
  - Selected area electron diffraction: 130 to 2,700 mm in 15 steps.
  - High dispersion diffraction: 4 to 80 m in 14 steps.
  - High resolution diffraction: 337 mm (EM-AD high resolution diffraction stage: optional).

2.2 Electron optical system

2.2.1 Illuminating system

- Electron gun (cool beam type)
  - Filament: Precentered hairpin type tungsten/LaB_6 filament, DC heating.
  - Bias: Self-bias, continuously variable.
  - Alignment: Electromagnetic 2-stage interlocking system.
  - Anode chamber airlock mechanism and electron gun lift: Built-in, pneumatic control.
- Condenser lens
  - Lens composition: Three-stage (double-gap 1st condenser lens, 2nd condenser lens and mini-lens).
  - Apertures: 20, 40, 70, 120, 200 μm in diameter (click-stop changeover).
  - Stigmator: Electromagnetic type, complete with centering device, seven circuits.
  - Alignment: Electromagnetic 2-stage interlocking system, four circuits.
- Beam tilting angle: Max. 4° in all directions.

2.2.2 Image forming system

- Image forming lens system: Rotation-free, electromagnetic 6-stage system (objective lens, OM lens, 1st, 2nd and 3rd intermediate lenses, projector lens).
- Aperture (molybedenum film)
  - Objective lens apertures: 20, 50, 80 μm in diameter (click-stop changeover).
  - Field limiting apertures: 20, 100, 300 μm in diameter (click-stop changeover).
- Stigmator: Electromagnetic type, complete with centering device; two circuits each for low magnification and standard magnification.

2.3 Specimen stage

- Specimen exchange: Airlock mechanism.
- Loading capacity: Two specimens.
- Specimen movement range
  - X and Y directions: ±1 mm (position of field of view under observation displayed on CRT).
  - Z direction: +0.2, −0.3 mm
- Specimen tilt angle: ±30° (X tilt).

2.4 Camera chamber

- Film
  - Standard size: 65 mm × 90 mm.
  - Large size: 80.9 mm × 99.6 mm (available to order).
  - Loading capacity: Up to 50.
  - Feeding: Fully automatic (single film feeding also possible).
  - Exchange mechanism: Airlock type.
- Exposure: Automatic exposure (manual exposure also possible).
- Data recording: Film number, magnification/camera length, accelerating voltage, micron bar and calibrated length, and characters (keyboard entry).

2.5 Vacuum system

- Vacuum pumps: Oil rotary pump, ion pump and oil diffusion pump.
- Ultimate pressure: 10^{-5} Pa (specimen chamber).
- Vacuum gauges: Penning and Pirani gauges.
- Vacuum valves: Automatically controlled pneumatic and solenoid valves.

2.6 Installation requirements

2.6.1 Power supply cooling water

- Power supply: Single phase, 200/220/240 V, 50/60 Hz, 6.5 kVA.
- Grounding terminal: 100 Ω or less, 1.
- Cooling water
  - Flow rate: 5 to 7 ℓ/min. obj 0,8 ℓ/min, ostatní čočky 0,8 ℓ/min
  - Pressure: 0.1 to 0.5 MPa (gauge pressure).
  - Temperature: 15 to 20°C.
  - Faucet: 14 mm O.D. (for 1/2" hose), 1.

2.6.2 Installation room

- Floor space: 2,800 mm (width) × 3,000 mm (depth) or more.
- Ceiling height: 2,700 mm or more.
- Doorway: Width: 800 mm or more.
  Height: 1,800 mm or more.
- Room temperature: 20 ± 5°C.
- Humidity: Below 60%.
- Tolerable external magnetic fields: Less than 0.1 μT.
- Floor strength: Better than 3.5 kPa.
- Compressed air: 0.35 to 0.45 MPa (gauge pressure).

2.6.3 Dimensions and weight (mm and kg)

	Width	Depth	Height	Weight
Console	1,990	1,420	2,670*	1,150
Power supply	921	700	1,250	175
Pump box	360	240	510	55
HT tank	720	510	1,350	150

* The height when the electron gun is hoisted.

2.7 Warranty

With the exception of damage resulting from natural disasters and careless handling, this instrument is guaranteed for a period of one year from the time of installation, and any and all faults or failures occurring during this period will be repaired free of charge at the installation site.

Note: These specifications are subject to change without notice.

3. COMPOSITION AND CONSTRUCTION

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3.1 Composition

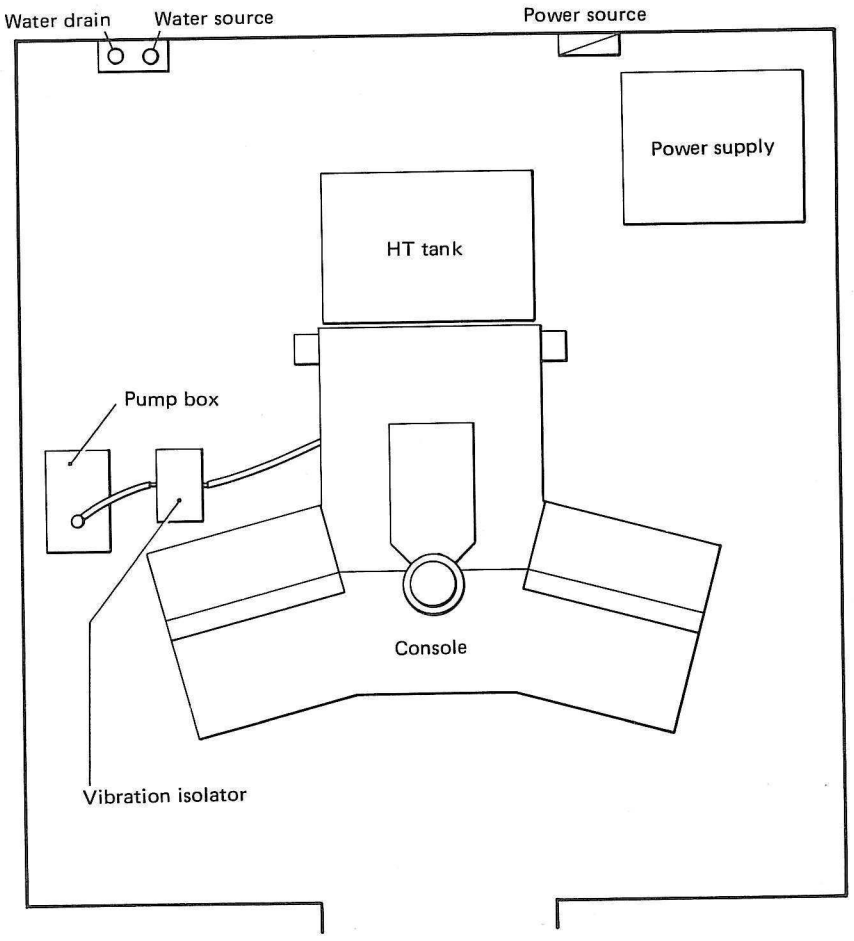


Fig. 3.1-1 Composition and layout diagram

3.2 Accessories

Although some of the items are not used by the users, they should nevertheless be carefully stored as they will be required for servicing purposes.

Name	Purpose
Boat	For cleaning aperture foils
Washers	For attaching the boat
Specimen grid case	(Optional)
Lever	For assembling camera chamber parts
Suction disks	For removing the window glass
Hand blower	For removing dust
Tweezers	(Optional)
Fomblin grease	For lens system O-rings
Apiegon grease	For O-rings in other than lens system
Silicone grease	For coating the electron gun insulator

Name	Purpose
Funnel	(Optional)
Refrigerant drainer	(Optional)
Small fluorescent screen (encased)	Spare
Wehnelt adjusting tool	Used for adjusting the Wehnelt cap-filament distance
OL pole piece setting tool	Used for installing and removing the objective lens pole piece
PL pole piece setting tool	Used for installing and removing the projector lens pole piece
OL pole piece	For standard use
OL pole piece	(Optional)
Apertures	Condenser lens apertures, objective lens apertures and field limiting apertures
Lens tools	Used for disassembling the column
Compass wrench	Used for tightening and loosening special screws (nuts)
Special hex keys	Used for tightening and loosening screws located in narrow places
Flat-bars and screws	Used for linking the column with the lift
Evacuation pipe tool	Used for removing evacuation pipe
Flange tool	Used for removing special flanges
Tool box	For storing the above tools

No.	Name	Purpose
Fig. 3.2-1		
①	Freon gas	For the electron gun gas chamber and HV tank
②	Lens lifting tool	For disassembling and reassembling the anode chamber and lenses
③	Hoist and support	For hoisting the column and HV generating tank interior parts (max. load 100 kg)
④	Wire rope with hook	For hoisting the HV generating tank inner part

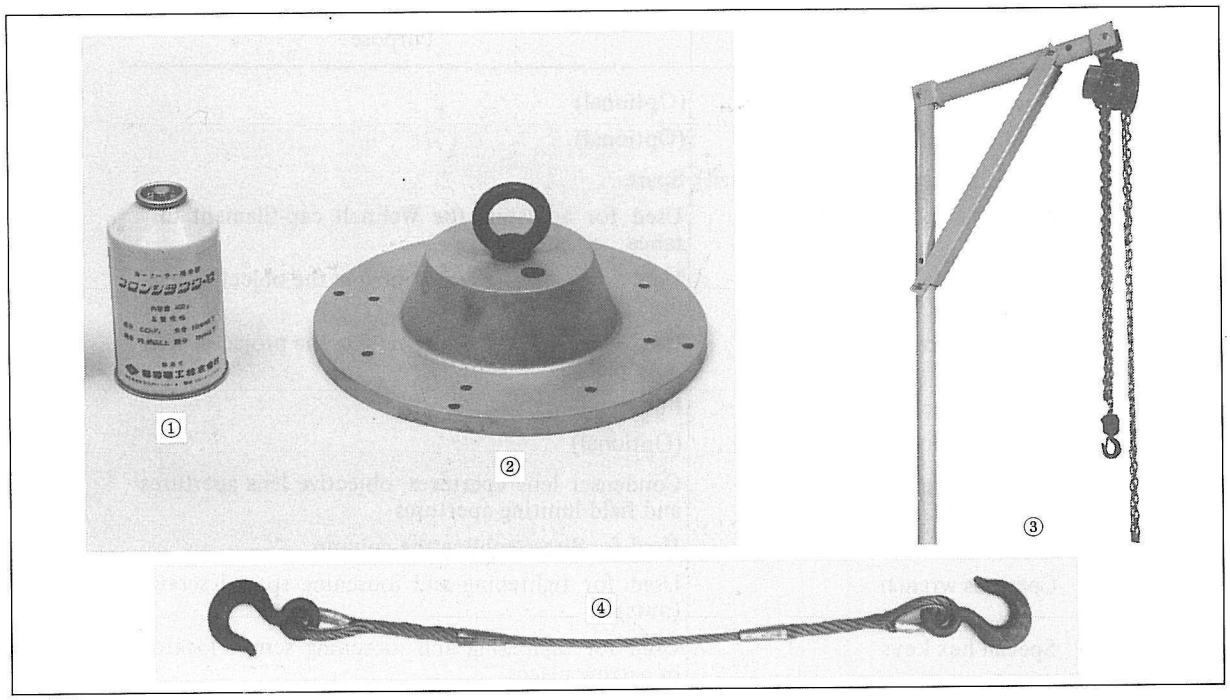


Fig. 3.2-1 Accessories

3.3 Construction of column

3.3.1 Column exterior

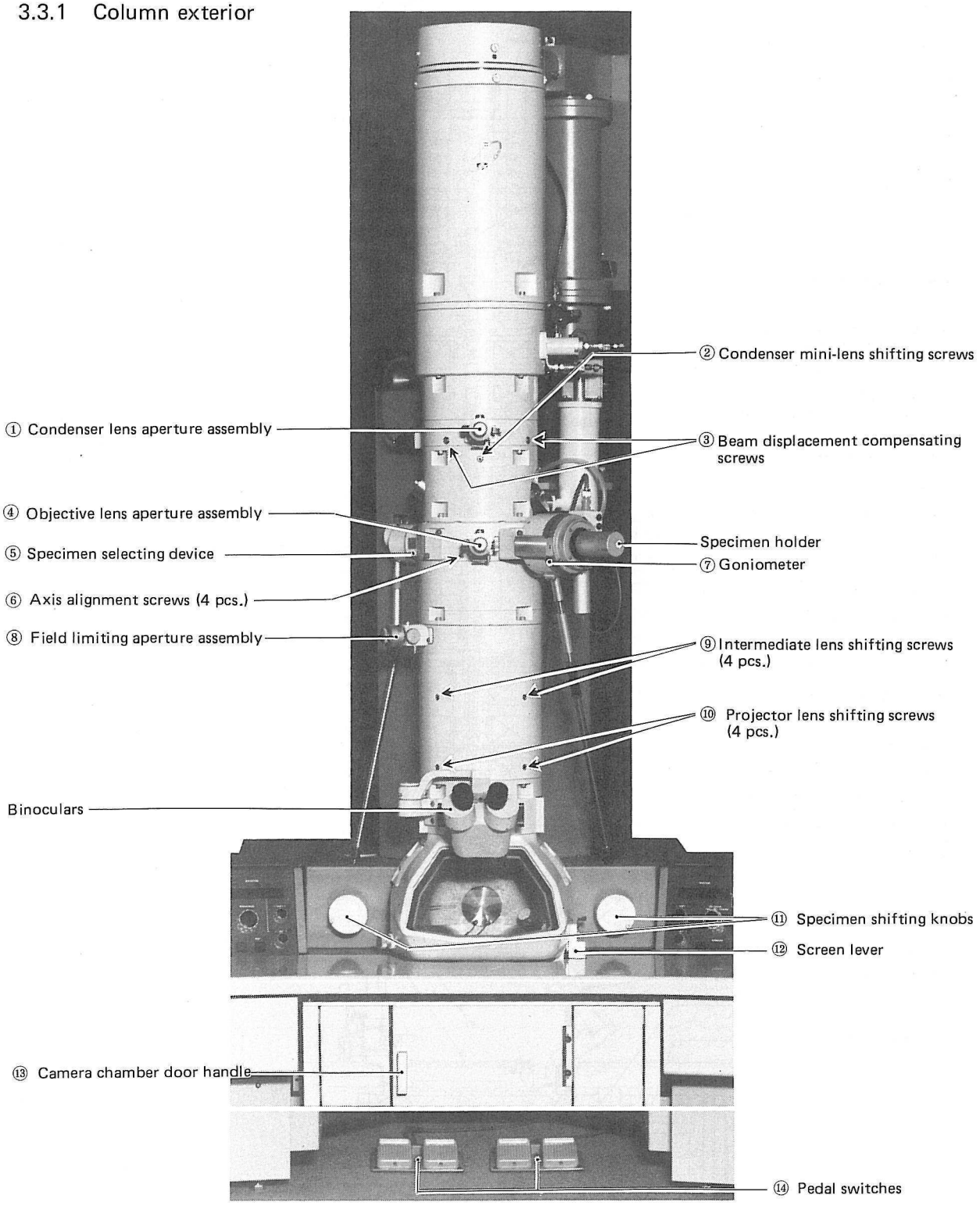


Fig. 3.3-1 Column Exterior (with attachments)

3.3.2 Column interior

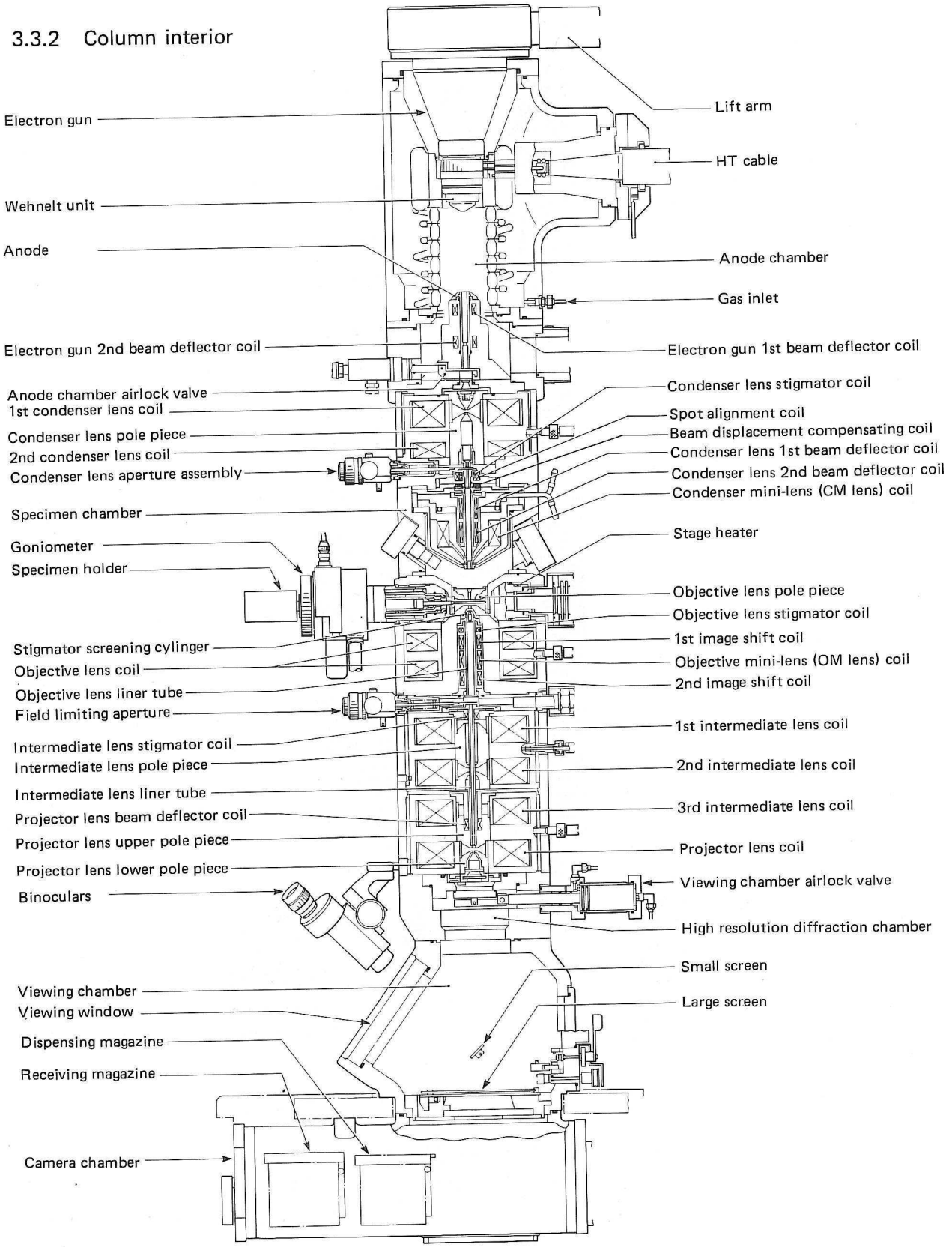


Fig. 3.3-2 Cross section of column (side entry type)

3.3.3 Location of coils and lenses

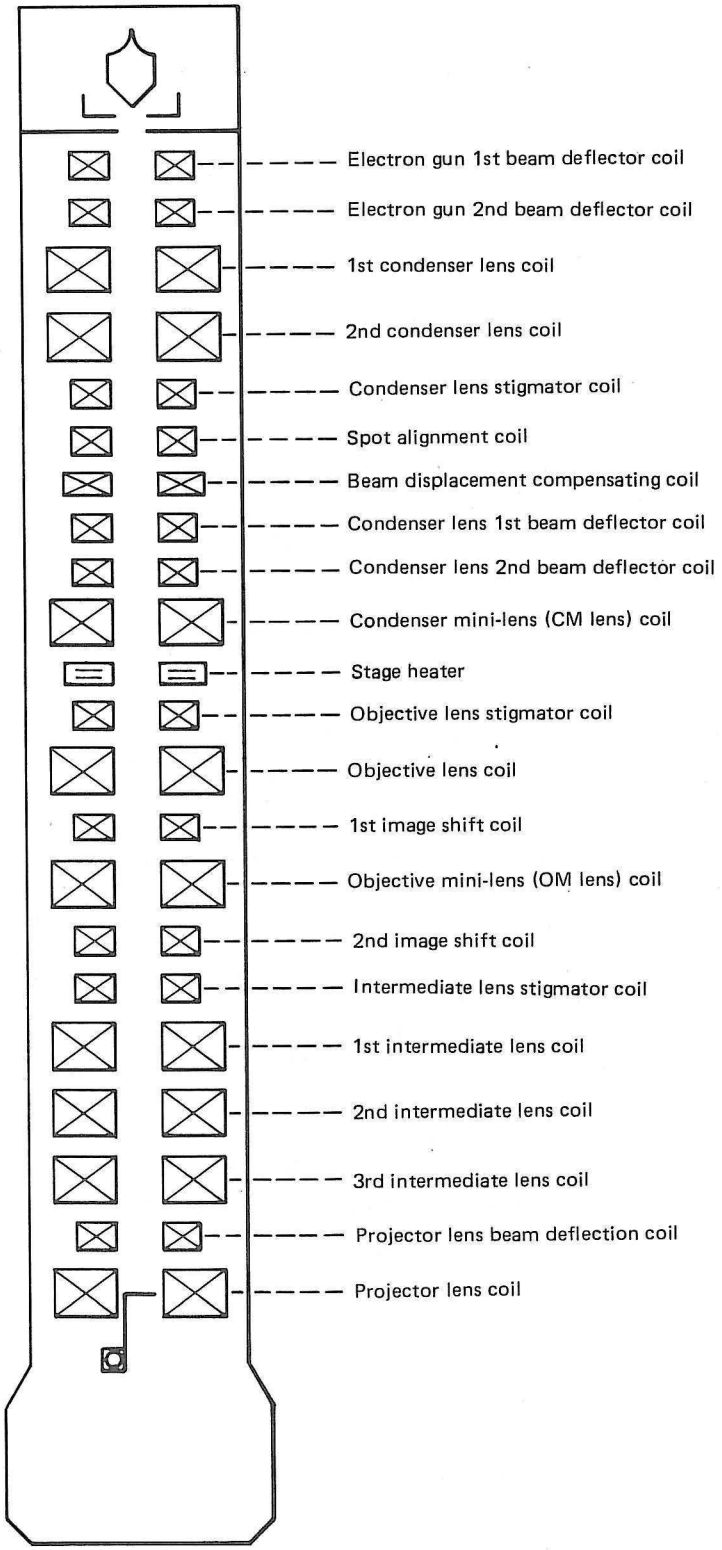


Fig. 3.3-3 Location of coils and lenses

3.4 Location of control panels

Control panels L2 and R2 are accessible by opening covers L2 and R2. Cover L2 opens when the right upper corner of the cover is tapped and cover R2 opens when the left upper corner of the cover is tapped. The key board and gun align appear when control panel R2 is drawn out.

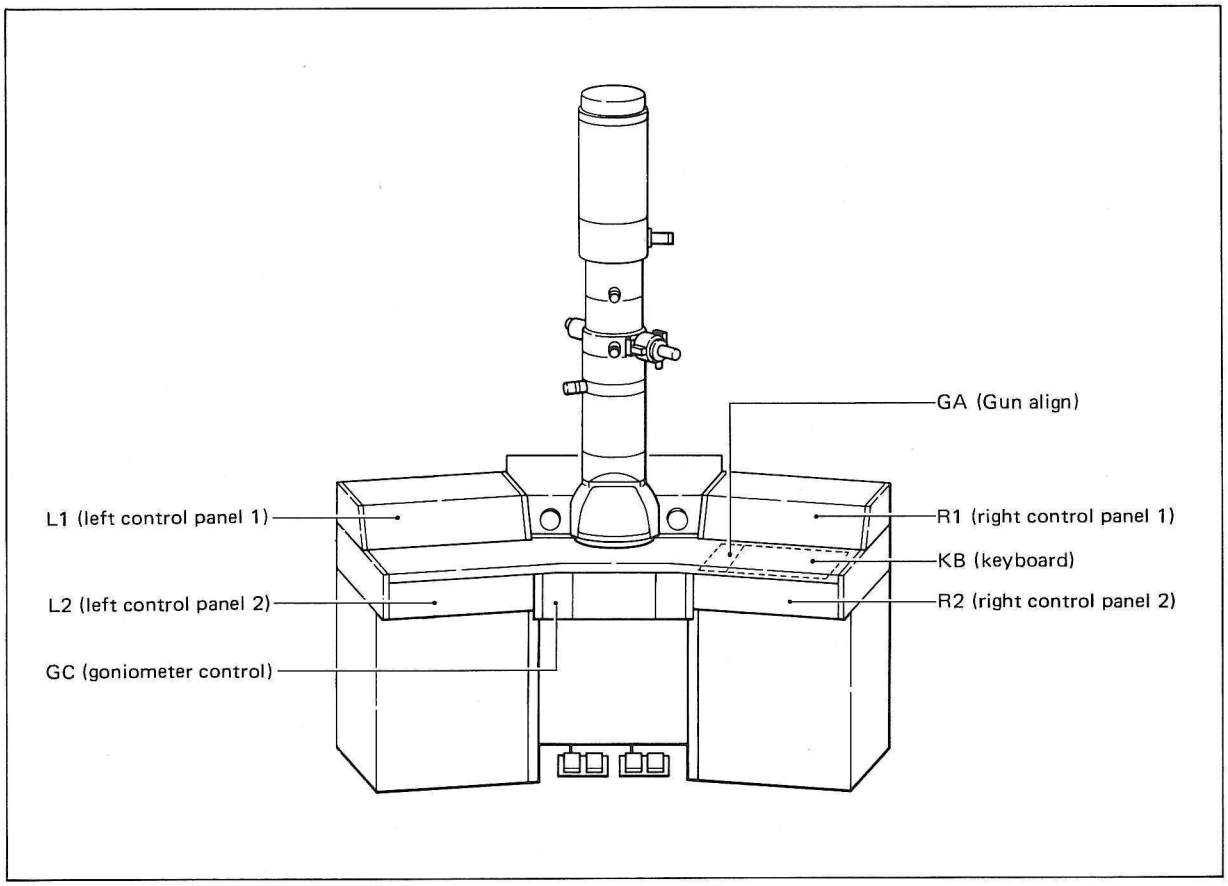
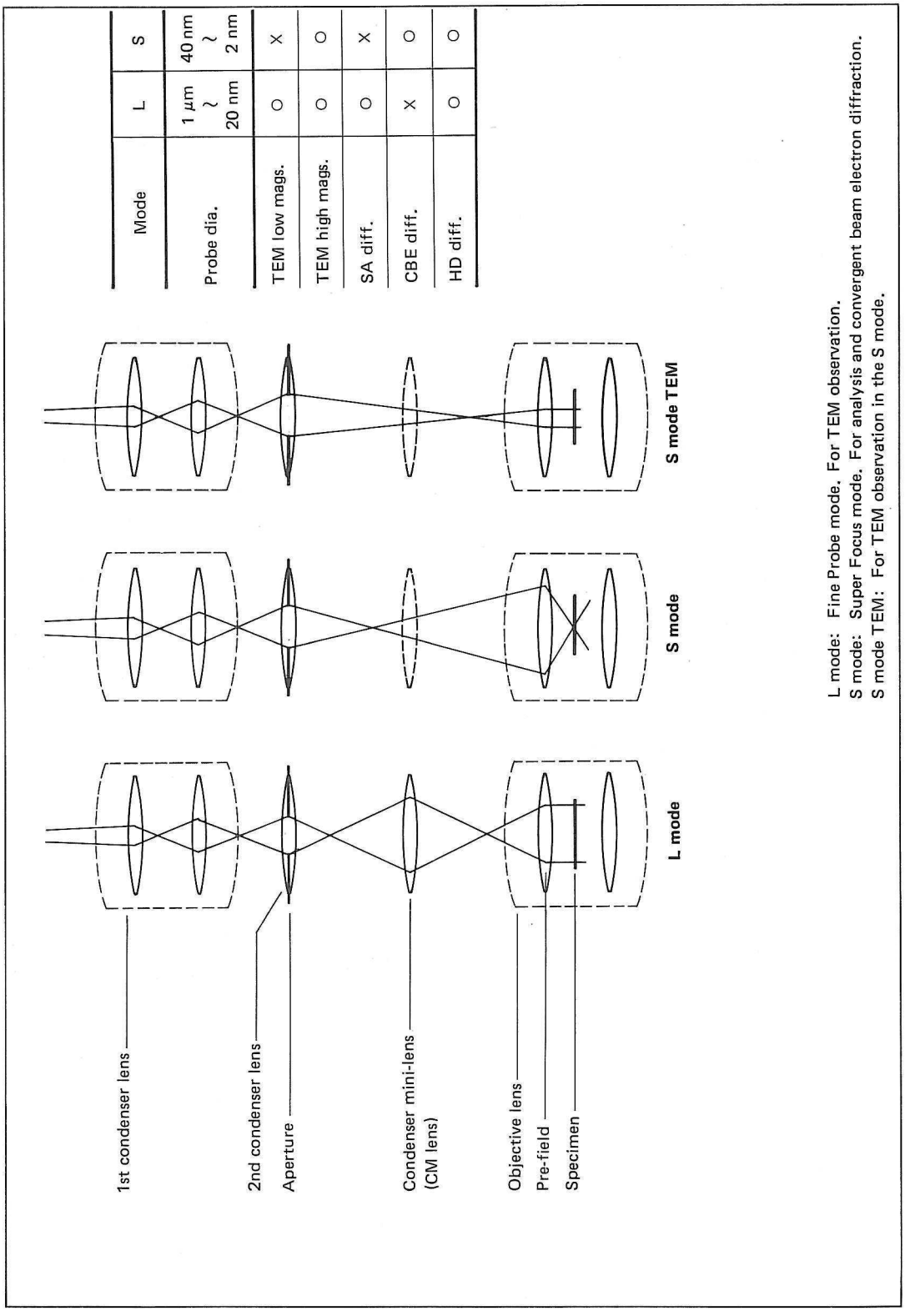


Fig. 3.4-1 Location of control panels

3.5 Ray diagram

3.5.1 Illumination system



Mode	L	S
Probe dia.	1 μm ~ 20 nm	40 nm ~ 2 nm
TEM low mags.	O	X
TEM high mags.	O	O
SA diff.	O	X
CBE diff.	X	O
HD diff.	O	O

L mode: Fine Probe mode. For TEM observation.
S mode: Super Focus mode. For analysis and convergent beam electron diffraction.
S mode TEM: For TEM observation in the S mode.

Fig. 3.5-1 Ray diagrams (illumination system)

3.5.2 Image forming system

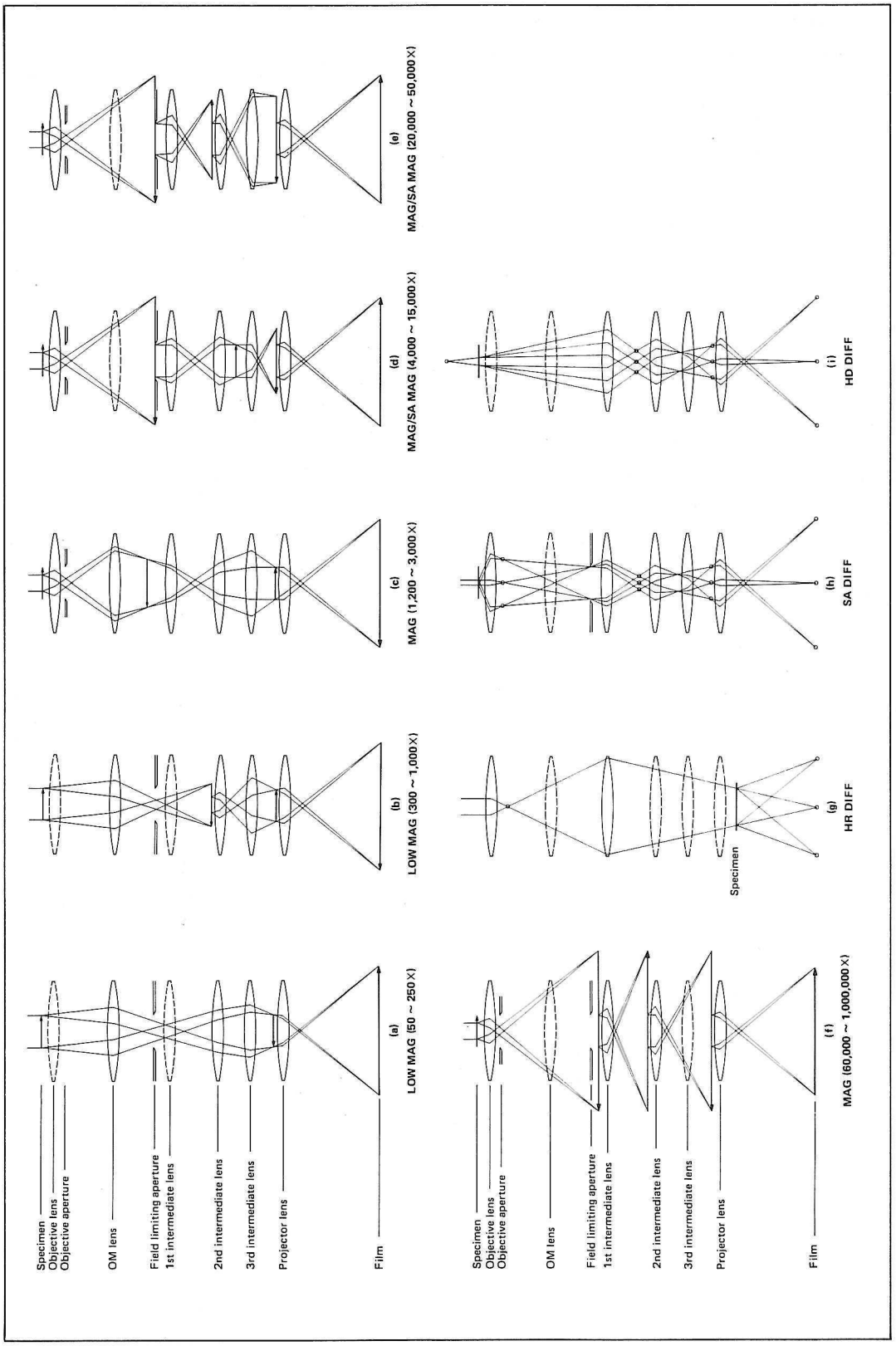


Fig. 3.5-2 Ray diagrams (image forming system)

4. DESCRIPTION OF COLUMN AND PANEL CONTROLS

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4.1 Column (see Fig. 3.3-1)

No.	Name	Description
①	Condenser lens aperture assembly Knob 1 and lever	(see Fig. 4.1-1) The apertures are selected corresponding to the knob 1 position and lever direction.
	Knobs 2, 3, 4	Knobs 2 and 3 are used to move the apertures in X and Y directions when the lever is turned to the left. Knobs 2 and 4 are used when the lever is turned to the right.

Lever direction	Left			Right		
Knob 1 position						
Aperture size	○ 200	○ 170	○ 70	○ 40	○ 20	∞

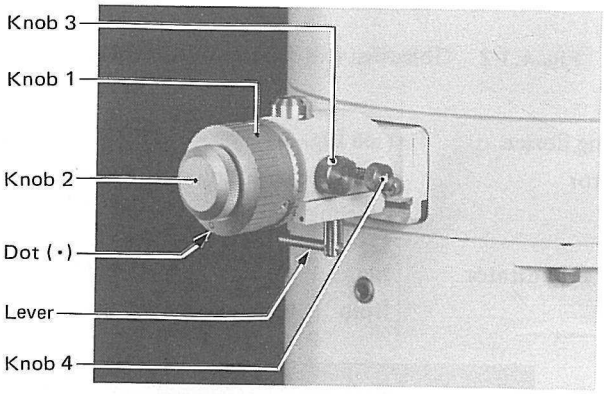


Fig. 4.1-1 Condenser lens aperture assembly

②	Condenser mini-lens shifting screws	For illumination system alignment.
③	Beam displacement compensating screws	Used for compensating for electron beam shift which results when the OBJ FOCUS knob (control panel R1) is manipulated.

No.	Name	Description
④	Objective lens aperture assembly Knob 1 and Lever	(see Fig. 4.1-2) The apertures are selected corresponding to the knob 1 position and lever direction.

Lever direction	Left			Right
Knob 1 position				Any position
Aperture size	○	○	○	∞

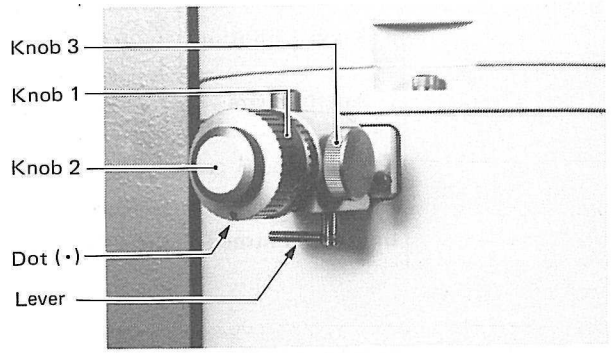


Fig. 4.1-2 Objective and field limiting aperture assemblies

⑤	Specimen selecting device Specimen selector	(see Fig. 4.1-3) Used for selecting either one of the two specimens mounted on the specimen holder.
	Specimen number indicator	Indicates which specimen (1 or 2) is being observed. Changeover from 1 to 2 or 2 to 1 is effected by manipulating the specimen

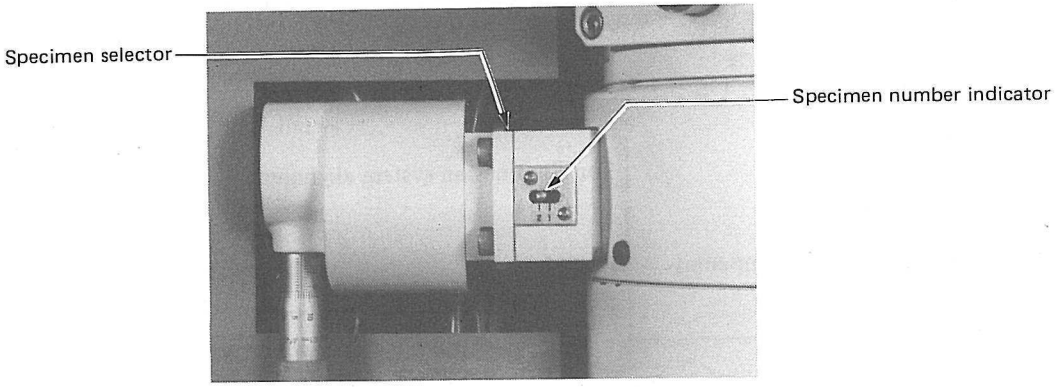


Fig. 4.1-3 Specimen selecting device

No.	Name	Description
		selector. 1 and 2 on the indicator correspond to the engraved numbers 1 and 2 on the specimen holder.
⑥	Axis alignment screws (4 pcs.)	Used for aligning the specimen tilt axis.
⑦	Goniometer	(see Fig. 4.1-4)
	X-tilt knob	Used for tilting the specimen around the X axis (i.e., around the axis of the specimen holder).
	Z control knob	Used for shifting the specimen vertically.
	X-tilt angle limiting screws (2 pcs.)	Used for confining the X-tilt angle.
	Lamp	Lights up when the motor is coupled to the goniometer.
	Motor	Drives the goniometer.

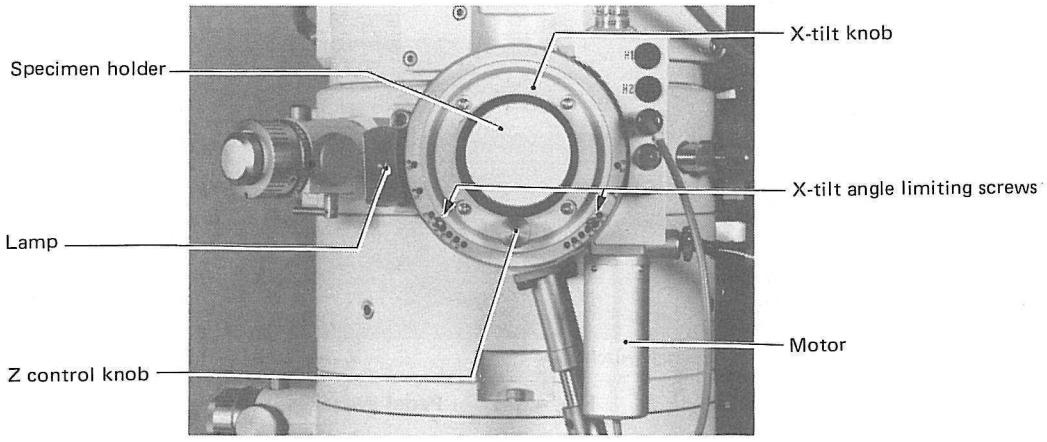


Fig. 4.1-4 Goniometer

⑧	Field limiting aperture assembly	Used for selecting, positioning, and aligning the field limiting apertures. See the description of the objective lens aperture assembly.
⑨	Intermediate lens shifting screws (4 pcs.)	Used for aligning the image forming system.
⑩	Projector lens shifting screws (4 pcs.)	Used for aligning the image forming system.
⑪	Specimen shifting knobs	Used for shifting the specimen to select the desired field of view. The position of the selected firld of view is displayed on the CRT (PAGE-2) on control panel R1 (Sect. 4.2.5).

No.	Name	Description
⑫	Screen lever	Used for changing the small fluorescent screen position.
⑬	Camera chamber door handle	Used for opening and closing the camera chamber door. By turning the handle clockwise as far it will go, air is admitted into the viewing and camera chambers, and the camera chamber door opens. By turning the handle fully counterclockwise with the door kept closed by hand, the two chambers are evacuated.
⑭	Pedal switches X pedal switches	(see Fig. 4.1-5) By stepping on one of the pedals, the specimen is tilted around the X-axis in one direction and by stepping on the other pedal, the specimen is tilted around the X-axis in the opposite direction.
	Y pedal switches	When a specimen rotation holder is used, the specimen is rotated in one direction by stepping on one of the pedals and rotated in the opposite direction by stepping on the other pedal. When a specimen tilt holder is used, the specimen is tilted around the Y-axis (perpendicular to the axis of the specimen holder) in one direction by stepping on one pedal and tilted around the Y-axis in the opposite direction by stepping on the other pedal. Further, when a specimen elongating holder is used, the specimen is elongated by stepping on one pedal and compressed by stepping on the other pedal.

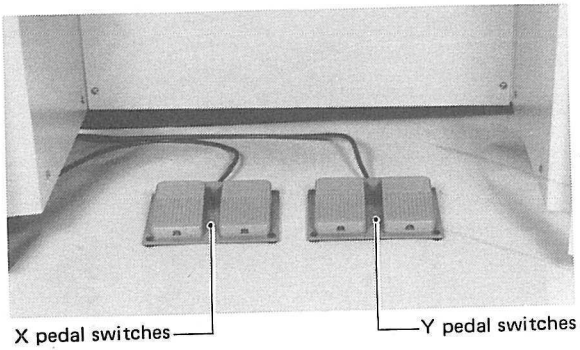


Fig. 4.1-5 Pedal switches

4.2 Control panels (see Fig. 3.4-1)

4.2.1 Control panel L1

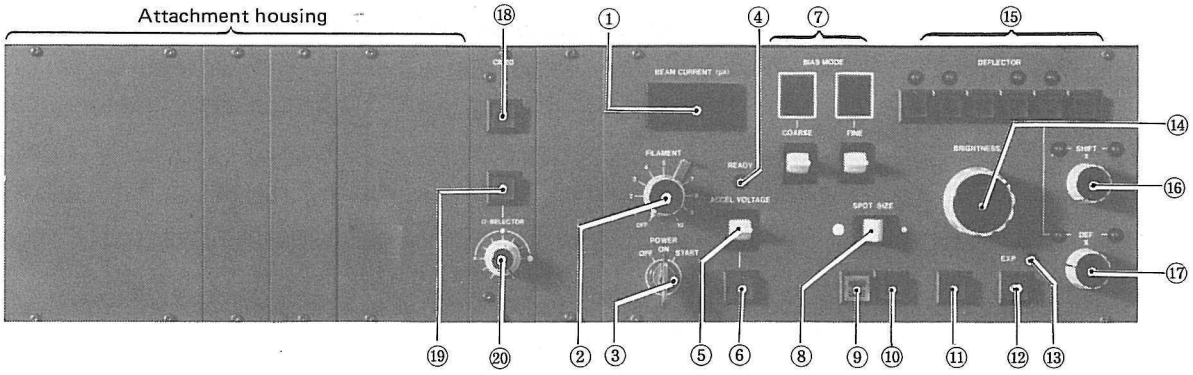


Fig. 4.2-1 Control panel L1

No.	Name	Description
L1-①	BEAM CURRENT	Indicates the sum of the beam current and the high voltage detecting current.
L1-②	FILAMENT	Used for controlling the electron gun filament heating current.
L1-③	POWER	Microscope main power switch.
L1-④	READY	Indicates that the microscope is ready for high voltage generation.
L1-⑤	ACCEL VOLTAGE	Setting this switch to the upper position raises the high voltage, and setting the switch to the lower position lowers the high voltage.
L1-⑥	HT	By depressing this button, the high voltage is switched on and the lamp lights up. By releasing the button, the high voltage is switched off and the lamp goes out.
L1-⑦	BIAS MODE (COARSE and FINE)	Used for selecting the electron gun bias. Setting either of these switches to the upper position increases the beam current (the value indicated by the indicators also increases), and brightens the image.
L1-⑧	SPOT SIZE	Setting this switch to the left position increases the spot size, and setting the switch to the right position decreases the spot size. The spot size value is displayed on the CRT (PAGE-1*) on control panel R1.

* See Sect. 4.2.8.

No.	Name	Description
L1-⑨	ROOM LIGHT	Used for turning on/off the room light.
L1-⑩	BRIGHT ZOOM	For the zoom circuit (see Subsect. 5.6.5).
L1-⑪	BRIGHT 16X	When this switch is turned on, the built-in lamp lights up and both the 2nd condenser lens current range (variable by the BRIGHTNESS knob on control panel L1) and the stigmator coil current range (variable by the OBJ STIG 1 and 2 on control panel L1) expand 16 times.
L1-⑫	PHOTO	By depressing this switch when the lamp is unlit, a film is advanced to the exposing position and the lamp lights up. By depressing this button when the lamp is lit, the film is exposed and after the exposure, the film is advanced from the exposing position and the lamp goes out.
L1-⑬	EXP	This lamp lights up and remains lit while the shutter is open.
L1-⑭	BRIGHTNESS	Used for converging and spreading the electron beam by varying the 2nd condenser lens current. The variable current range expands 16 times when the BRIGHT 16X switch (control panel L1) is turned on.
L1-⑮	DEFLECTOR	When one of these buttons is depressed, the depressed button lamp brightens and the current of the coil relating to the depressed button becomes variable with the DEF: X knob (control panel L1) and DEF: Y knob (control panel R1). The lamp darkens and the coil current is fixed when the button is released.
	OBJ STIG 1	Used when varying the objective lens stigmator coil current (or the intermediate lens stigmator coil current in the case of LOW MAG mode). By depressing this button, stigmator circuit 1 is actuated, the built-in lamp brightens, and the green lamp above the button lights up. The green lamp remains lit until the OBJ STIG 2 button is depressed. The variable current range expands 16 times when the BRIGHT 16X switch (control panel L1) is turned on.
	OBJ STIG 2	Same as the OBJ STIG 1 button except that stigmator circuit 2 is actuated by depressing this button. The green lamp remains lit until the OBJ STIG 1 button is depressed.
	COND STIG	Used when varying the condenser lens stigmator coil current.
	DARK TILT	Used when varying the condenser lens 1st and 2nd beam deflector coil current. By depressing this button, the condenser lens beam deflector DARK circuit is actuated, the built-in lamp brightens, and the green lamp above the button lights up. The green lamp remains lit until the BRIGHT TILT button is depressed.

No.	Name	Description
	BRIGHT TILT	Same as the DARK TILT button except that the condenser lens beam deflector BRIGHT circuit is actuated by depressing this button. The green lamp remains lit until the DARK TILT button is depressed.
	IMAGE SHIFT	Used for slightly shifting the field of view. By depressing this button, the 1st image shift coil power supply circuit is connected to DEF: X and Y, and the built-in lamp brightens. This button is effective only when the FUNCTION: MAG 1 or MAG 2 button (control panel R1) is depressed.
L1-⑯	SHIFT: X	Used for shifting the electron beam in the X direction by varying the condenser lens 1st beam deflector coil current. When this knob is set to its midway position, the left and right directional indicator lamps light up and when the knob is turned counterclockwise from the midway position the left lamp lights up and when it is turned clockwise the right lamp lights up.
L1-⑰	DEF: X	Used for varying the current of the X coil of the one set of coils selected by DEFLECTOR (control panel L1). When this knob is set to its midway position, the left and right directional indicator lamps light up and when the knob is turned counterclockwise from the midway position the left lamp lights up and when it is turned clockwise the right lamp lights up.
L1-⑱	CM	CM lens (condenser mini-lens) power switch.
L1-⑲	S	The lamp lights up, when depressed, indicating that the illumination mode is in the S mode. When redepressed, the lamp goes out and the illumination mode is turned into the L mode.
L1-⑳	α-SELECTOR	Selects the convergent angle with the illuminating area kept unchanged in size. The CM lens current decreases and illuminating angle becomes larger as this is turned clockwise. The CM lens current decreases to zero when this is turned fully clockwise. This does not function unless the S button is turned on.

4.2.2 Control panel R1

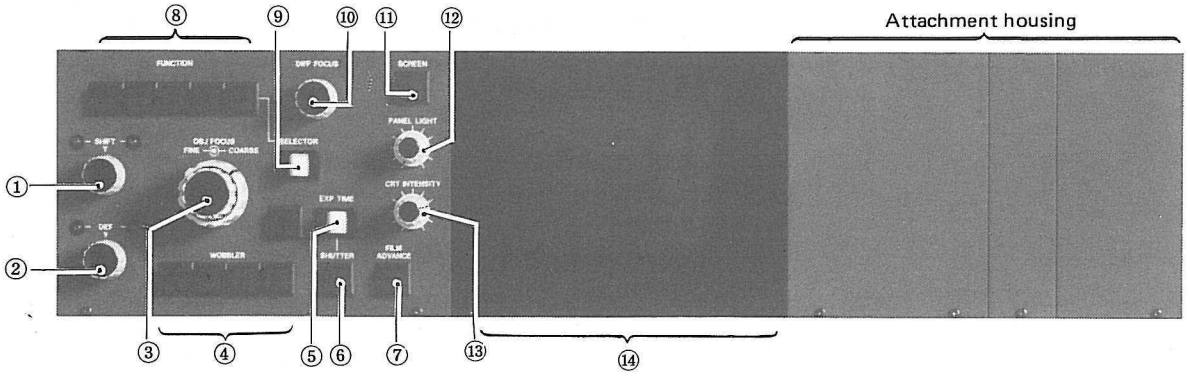


Fig. 4.2-2 Control panel R1

No.	Name	Description
R1-①	SHIFT: Y	Used for shifting the electron beam in the Y direction by varying the condenser lens 1st beam deflector coil current. When this knob is set to its midway position, the left and right directional indicator lamps light up and when the knob is turned counterclockwise from the midway position the left lamp lights up and when it is turned clockwise the right lamp lights up.
R1-②	DEF: Y	Used for varying the current of the Y coil of the one set of coils selected by DEFLECTOR (control panel L1). When this knob is set to its midway position, the left and right directional indicator lamps light up and when the knob is turned counterclockwise from the midway position the left lamp lights up and when it is turned clockwise the right lamp lights up.
R1-③	OBJ FOCUS	Used for adjusting the objective lens current (OM lens current in the case of LOW MAG mode) to focus the image.
	OBJ 16X	When this button is depressed, the button lamp lights up and the objective lens current range variable by the OBJ FOCUS knobs (control panel R1) enlarges 16 times.
R1-④	WOBBLER	Used for generating alternating current or imposing a small cyclic electrical variation on the related current or voltage.
	IMAGE X and Y	Used for focusing. The 1st beam deflector coil current and 2nd beam deflector coil current are made to be vary periodically when one of these buttons is depressed. If the image is out of foucs, it

No.	Name	Description
		wobbles in the X direction when the IMAGE X button is depressed and in the Y direction when the IMAGE Y button is depressed.
	OBJ	By depressing this button, the objective lens current is periodically varied, facilitating the current center alignment and astigmatism correction.
	HT	By depressing this button, the high voltage is periodically varied, facilitating the voltage center alignment.
R1-⑤	EXP TIME	Used for setting the exposure time in the manual exposure mode. Setting this switch to the left position decreases the exposure time, and setting the switch to the right position increases the exposure time. The exposure time set by this switch is displayed on the CRT (PAGE-1) on control panel R1.
R1-⑥	SHUTTER AUTO	When this button is depressed, the lamp lights up and the shutter is automtically controlled. When the button is released the lamp goes out and the shutter is controlled manually.
R1-⑦	FILM ADVANCE AUTO	When this button is depressed, the lamp lights up and unused films are successively advanced to the exposing position without depressing the PHOTO button (control panel L1). When the button is released, the lamp goes out and no film is advanced to the exposing position unless the PHOTO button is depressed.
R1-⑧	FUNCTION	Used for selecting an image forming mode. The magnification or camera length in the selected mode can be varied with the SELECTOR switch (control panel R1), and is displayed on the CRT (PAGE-1) on control panel R1. The magnification or camera length set by the SELECTOR switch is stored so that even if another mode is once selected, the magnification or camera length can be set to the stored value by selecting the original mode again.
	MAG 1	Used for selecting the normal magnification mode.
	MAG 2	By depressing this button, the basic magnification (see Subsect. 5.2.11q) is obtained. In this mode, the magnification can be increased or decreased from the basic magnification with the SELECTOR switch. The magnification set in this mode is not stored.
	LOW MAG	Used for selecting the low magnification mode.
	SAM/ROCK	Used for selecting the selected area magnification mode (or the rocking mode when the ASID scanning device is used).

No.	Name	Description
	DIFF	Used for selecting the diffraction mode. In this mode, a total of 30-step camera lengths can be selected with the SELECTOR switch, i.e. the camera lengths for selected area diffraction (15 steps), those for high dispersion diffraction (14 steps), and that for high resolution diffraction in the camera length ascending order. The selected camera length is displayed on the CRT (PAGE-1) on control panel R1.
R1-⑨	SELECTOR	Used for varying the normal magnification when the FUNCTION: MAG 1 or MAG 2 button (control panel R1) is depressed, the low magnification when the FUNCTION: LOW MAG button is depressed, the selected area magnification (or the rocking angle in case the ASID is used) when the FUNCTION: SAM/ROCK button is depressed, and the camera length when the FUNCTION: DIFF button is depressed. Setting this switch to the left position decreases the value and setting the switch to the right position increases the value. The magnification or camera length set by this switch is displayed on the CRT (PAGE-1) on control panel R1.
R1-⑩	DIFF FOCUS	Used for varying the 1st intermediate lens coil current for focusing the field limiting aperture when the FUNCTION: SAM/ROCK button (control panel R1) is depressed, and for focusing the diffraction pattern when the FUNCTION: DIFF button is depressed.
R1-⑪	SCREEN	Used for changing the large fluorescent screen position (horizontal or vertical). The built-in lamp lights up and remains lit while the screen is at the vertical position.
R1-⑫	PANEL LIGHT	When this knob is turned fully counterclockwise, the panel light goes out and when it is turned clockwise, the panel light becomes brighter.
R1-⑬	CRT INTENSITY	Used for adjusting the brightness of the CRT (control panel R1).
R1-⑭	CRT	Used for displaying information (see Sect. 4.2.8) as requested through the keyboard.

4.2.3 Control panel L2

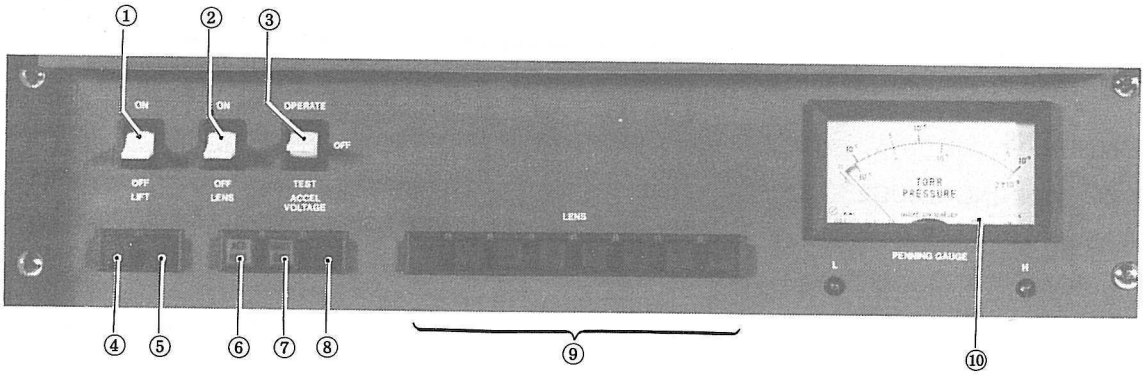


Fig. 4.2-3 Control panel L2

No.	Name	Description
L2-①	LIFT	Power on/off switch for the lift. By turning this switch ON and depressing the GUN AIR button (control panel L2), the lift is actuated to raise the electron gun.
L2-②	LENS POWER SUPPLY	By turning this switch OFF, the power supply circuits for all the lenses, beam deflector coils and stigmator coils are turned off and at the same time, the high voltage power supply is also turned off.
L2-③	ACCEL VOLTAGE	At OPERATE, the safety circuit for the high voltage is actuated, at TEST, the safety circuit is turned off and at OFF, the high voltage power supply is turned off.
L2-④	GUN AIR	The lamp lights up when this button is depressed and air is admitted into the anode chamber. When the LIFT switch (control panel L2) is set to ON, the lift is actuated to raise the electron gun after air is admitted into the anode chamber. When the button is released, the lamp goes out, the lift lowers to return the electron gun to its original position, and the anode chamber is evacuated.
L2-⑤	COL AIR	The lamp lights up and air is admitted into the column (except the viewing chamber) when this button is depressed. The lamp goes out and the column is evacuated when the button is released.
L2-⑥	ACD HEAT	Used for turning on/off the anticontamination device (optional) heating power.

No.	Name	Description
L2-⑦	BAKE OUT	Used for bake-out of the column.
L2-⑧	GUN SCAN	Used for finding the electron beam. The lamp lights up and the electron beam scans when this button is depressed.
L2-⑨	LENS	Power on/off switches for the respective lenses.
L2-⑩	PENNING GAUGE	Indicates the anode or specimen chamber pressure. When lamp H is lit, read the upper (outer) scale and when lamp L is lit, read the lower (inner) scale. See the EM-DCS/DVS Instruction Manual for further information.

4.2.4 Control panel R2

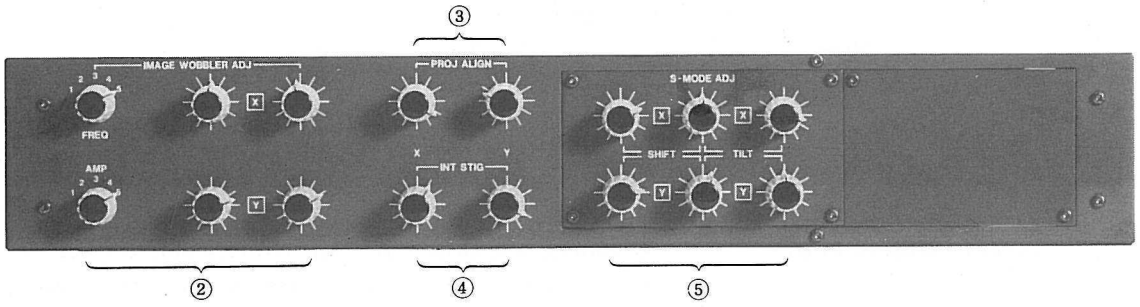


Fig. 4.2-4 Control panel R2

No.	Name	Description
R2- ②	IMAGE WOBBLER ADJ	Used for aligning the condenser lens 1st and 2nd beam deflector coils. A pulsating current flows through the coils when the IMAGE X or Y button (control panel R1) is depressed.
	FREQ, AMP	Select the frequency and amplitude of the pulsating current.
	X and Y	Aligns the coils in the X and Y directions. The X knob functions when the IMAGE X button is depressed and the Y knob functions when the IMAGE Y is depressed.
R2- ③	PROJ ALIGN: X and Y	Used for adjusting the projector lens beam deflector coil current in order to align the diffraction pattern center. These knobs are effective when the FUNCTION: DIFF button (control panel R1) is depressed.

No.	Name	Description
R2-④	INT STIG: X and Y	Used for correcting the intermediate lens astigmatism.
R2-⑤	S-MODE ADJ	For the column alignment in the S mode illumination system.
	SHIFT	Compensates diffraction pattern displacement when the SHIFT-X and Y (control panels L1 and R1) are turned.
	TILT	This is generally used at its midway positions.

4.2.5 Control panel GA

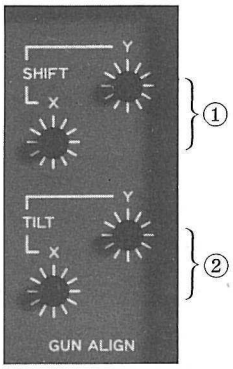


Fig. 4.2-5 Control panel GA

No.	Name	Description
GA-①	SHIFT: X and Y	Used for shifting the electron beam entering the condenser lens in order to align the electron gun with the condenser lens, by varying the electron gun 1st beam deflector coil current.
GA-②	TILT: X and Y	Used for tilting the electron beam entering the condenser lens in order to align the electron gun with the condenser lens, by varying the electron gun 1st and 2nd beam deflector coils currents.

4.2.6 Control panel GC

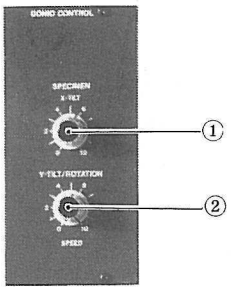


Fig. 4.2-6 Control panel GC

No.	Name	Description
GC-①	X-TILT	Used for varying the specimen tilting speed around the X-axis (i.e., around the axis of the specimen holder).
GC-②	Y-TILT/ROTATION	Used for varying the specimen tilting speed aroung the Y-axis (i.e., around the axis perpendicular to the axis of the specimen holder) when a specimen tilt holder is used, the specimen rotation speed when a specimen rotation holder is used, and the specimen elongation rate when a specimen elongating holder is used.

Key KR has been added to the left side next to the space key on the keyboard. this key is used to reset the computer when the computer operation through the keyboard is stopped.
The high voltage (accelerating voltage) must be regenerated after depressing the KR key.

4.2.7 Keyboard (KB)

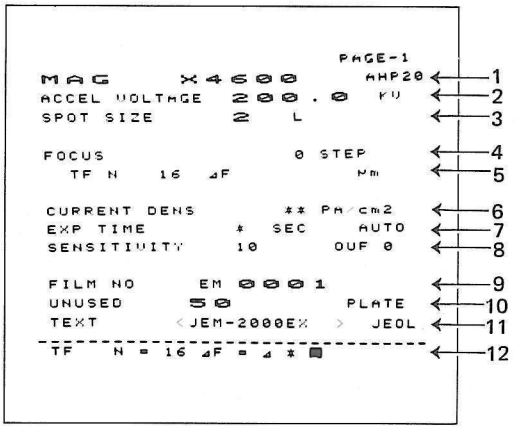
Fig. 4.2-7 Keyboard

No.	Name	Description
KB-①	PAGE	Every time this key is depressed, the PAGE displayed on the CRT (control panel R1) advances in the PAGE number in ascending order (PAGE-1 appears following PAGE-8). The displayed contents of each PAGE are as follows: PAGE-1: Magnification, type of objective lens pole piece, accelerating voltage, spot size, OBJ FOCUS knob position (step number), number of films to be exposed and focus step (step/film) for taking a through-focus series, current density on fluorescent screen, exposure time, exposure mode (automatic/manual), film sensitivity, OUF number, film number, number of unused films, type of camera, and TEXT (specimen name, etc.). PAGE-2: Specimen positions stored by the operator and the current specimen position (indicated by coordinates and graph). P and numbers represent the coordinates of the current position and stored positions, respectively. In the graph, the ■ mark and x marks indicate the current position and stored positions, respectively. PAGE-3: Open/closed status of each vacuum valve (indicated by vacuum system diagram) and readings of 4 Pirani gauges. PAGE-4: Voltage at each lens circuit check point. PAGE-5: Voltage at each beam deflector circuit check point. PAGE-6: Voltage at each stigmator circuit check point. PAGE-7: Operator's memorandum. The information written on this page is stored in the memory. PAGE-8: A part of PAGE-1.

No.	Name	Description
	THRU FOCUS	Used for setting the number of films to be exposed and the focus step (step/film) for taking a through-focus series. By depressing this key, "TF N" and "⊿F" are displayed on the bottom margin of PAGE-1. To set the number of films and focus step, make the CRT display "TF N" and "⊿F" in the bottom margin of PAGE-1 by depressing this button, input the desired values through the keyboard, and depress the RETURN key. If an input value is out of the allowable range, "ERROR" is displayed. In such case, redepress the THRU FOCUS key (the erroneous input value and "ERROR" are now erased), input a value within the allowable range, and depress the RETURN key. When the RETURN key is depressed, the characters on the bottom line are erased.
	F NO	Used for setting the film number and the number of unused films. By depressing this key, "FILM-NO" and "UNUSED" are displayed in the bottom margin of PAGE-1. Then, input the film number and the number of unused films on the right of "FILM-NO" and "UNUSED", respectively, through the keyboard, and depress the RETURN key. If a number out of the allowable range is input, "ERROR" is displayed. In such case, redepress the F NO key (the input number and "ERROR" are now erased), input a proper number, and then depress the RETURN key. When the RETURN key is depressed, the characters on the bottom line are erased and the input numbers are stored in the memory.
	TEXT	Used for writing information on the TEXT line of PAGE-1 and on any line of PAGE-7. By depressing this key once, "TEXT" is displayed in the bottom margin of PAGE-1 and by depressing this key twice, PAGE-7 is displayed. Further, by depressing this key three or more times, the information on PAGE-7 is erased. If information is to be written on the TEXT line of PAGE-1, depress this key once to make the CRT display "TEXT" in the bottom margin of PAGE-1, input required characters and symbols through the keyboard (see KB- 2), and depress the RETURN key. By so doing, the TEXT information written at the bottom moves to the TEXT line, and is stored in the memory. At the same time, "TEXT" displayed at the bottom is erased.
	PRINT	By depressing this key, the information displayed on the CRT is recorded by the printer (optional attachment).
KB-②	BACK SPACE	Used for column alignment (Subsect. 5.3.2).
	LINE FEED	When depressed, the cursor on PAGE-7 moves downwards (Subsect. 5.2.11f).
	CTRL	Used to display the * mark on PAGE-1 (Subsect. 5.2.11e).
	RETURN	See Subsect. 5.2.11.
	SHIFT	Used to display the upper one of two characters on the key.
	H TAB	Not used.

No.	Name	Description
	ESC	Used to suspend the automatic operation being carried out as requested through the key board.
	← and →	Used to move the cursor on the CRT left and right.
	Space key	Used to erase the character under the cursor on the CRT.
	Other keys	Used to typewrite the desired characters under the cursor on the CRT.

4.2.8 CRT display



1: Next to "MAG", the magnification (or camera length) is displayed. The value of magnification or camera length can be varied by manipulating the SELECTOR switch (control panel R1). The displayed value is printed on the film.

At the right end of this line, the name of the objective lens pole piece being used is displayed (Subsect. 5.2.11e).

2: The accelerating voltage displayed on this line is generated by depressing the HT button (control panel L1). The accelerating voltage can be varied by manipulating the ACCEL VOLTAGE switch (control panel L1), and the displayed value is printed on the film.

3: A number indicating the electron beam spot size and an L or S indicating the illumination mode are displayed. The spot size can be varied by manipulating the SPOT SIZE switch (control panel L1). The larger the displayed number, the smaller the spot size. The illumination mode (L or S) is changed with the S button (control panel L1).

4: The OBJ FOCUS knob (control panel R1) turning amount is displayed in terms of number of OBJ FOCUS: FINE knob steps. (When the OBJ 16X button switch is on, the amount is not displayed). The displayed number is set to 0 when any of the magnification, accelerating voltage and imaging mode is changed.

5: The number of films to be exposed, an amount of focus change per notch of the OBJ FOCUS: FINE knob (control panel R1), and a number of OBJ FOCUS: FINE knob notches per film for taking a through-focus series are displayed. The displayed values can be varied through the keyboard (Subsect. 5.2.11n).

6: The current density on the film is displayed.

7: Next to "EXP TIME", the exposure time is displayed. In the case of manual exposure, the displayed value can be varied by manipulating the EXP TIME switch (control panel R1). At the end of this line, "AUTO" (auto-

matic exposure) or "MANUAL" (manual exposure) is displayed. The desired exposure mode can be selected with the SHUTTER AUTO button (control panel R1).

8: Next to "SENSITIVITY", a number indicating the exposure meter sensitivity is displayed. The ~~larger~~ shorter the displayed number, the lower the sensitivity and the longer the exposure time. The sensitivity can be varied through the keyboard (Subsect. 5.2.11ℓ). Next to "OUF", an OUF number is displayed (Subsect. 5.2.11o).

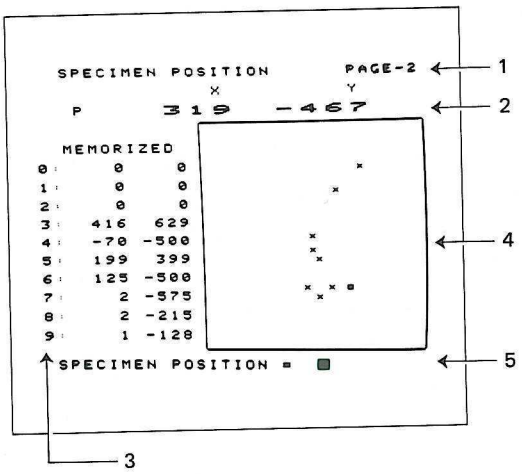
9: The film number is displayed. Every time a film is exposed, the displayed number (low order four digits) advances by one. The film number can be changed through the keyboard and nonnumeric characters can be written into high order two digits (Subsect. 5.2.11j). The displayed value is printed on the film.

10: Next to "UNUSED", the number of unused films is displayed. Every time a film is exposed, the displayed number is reduced by one. This number can be changed through the keyboard (Subsect. 5.2.11j).
At the right end of this line, the type of film (camera) as selected with keyboard is displayed (Subsect. 5.2.11k).

11: On this line, the operator can write the specimen name, etc. through the keyboard. The displayed contents are printed on the film (Subsect. 5.2.11g).

12: A desired character can be written through the keyboard at the position marked with ■. By depressing the ← or → key, the ■ mark can be shifted leftward or rightward and by depressing the space key, the character in the ■ mark can be erased. Further, by depressing the RETURN key, the characters written on this line are erased and are stored in the memory.

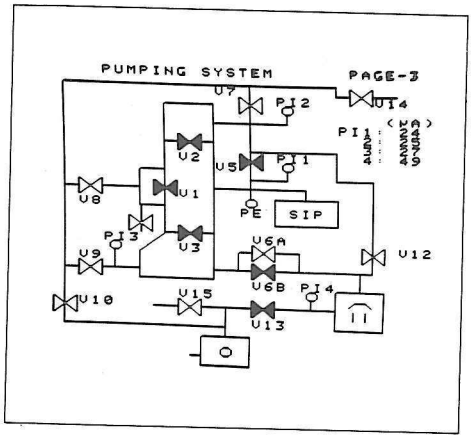
PAGE-2 is displayed by depressing the SP PO key on the keyboard.



1: X means the horizontal direction on the CRT or the X direction (specimen holder axial direction) on the specimen. When the left specimen shifting knob is turned, the specimen horizontally shifts on the CRT. Y means the vertical direction on the CRT.

2: The coordinates of the current specimen position are displayed. The current specimen position is represented by the ■ mark in the graph.

3: The coordinates of each stored specimen position are displayed. The stored specimen positions are represented by the x marks in the graph.



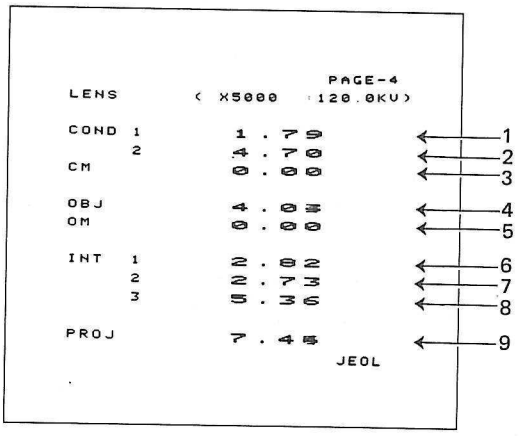
4: A circle inscribed in this frame corresponds to the specimen grid size.

5: This is displayed by depressing the keyboard (see Subsect. 5.2.11i).

PAGE-3 shows the status of the vacuum system.

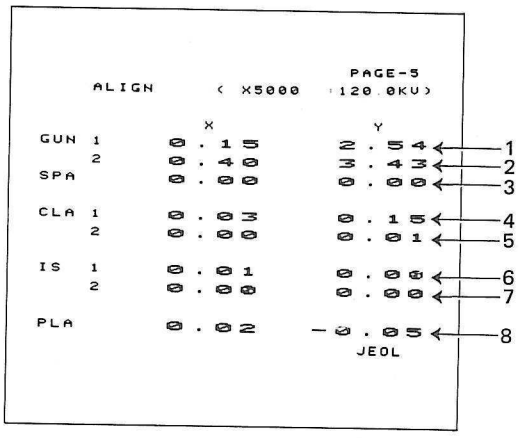
⋈ : Indicates that the valve is closed.

⋈ : Indicates that the valve is open.



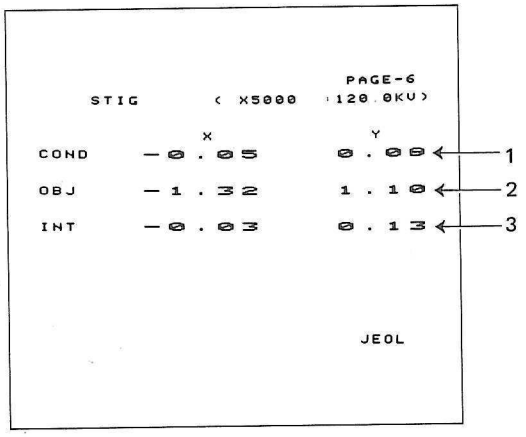
PAGE-4 shows the voltage at each lens circuit check point.

1: 1st condenser lens
2: 2nd condenser lens
3: Condenser mini-lens
4: Objective lens
5: OM lens
6: 1st intermediate lens
7: 2nd intermediate lens
8: 3rd intermediate lens
9: Projector lens



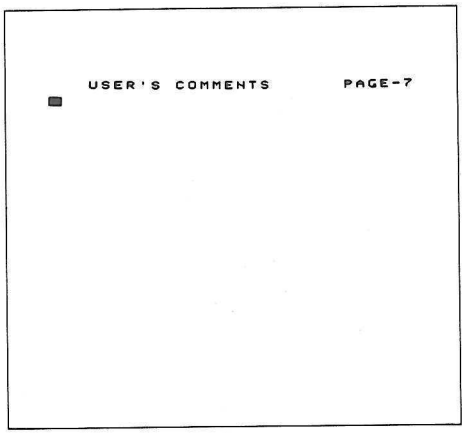
PAGE-5 shows the voltage at each beam deflector circuit check point.

1: Electron gun 1st beam deflector coil
2: Electron gun 2nd beam deflector coil
3: Spot alignment coil
4: Condenser lens 1st beam deflector coil
5: Condenser lens 2nd beam deflector coil
6: 1st image shift coil
7: 2nd image shift coil
8: Projector lens beam deflector coil



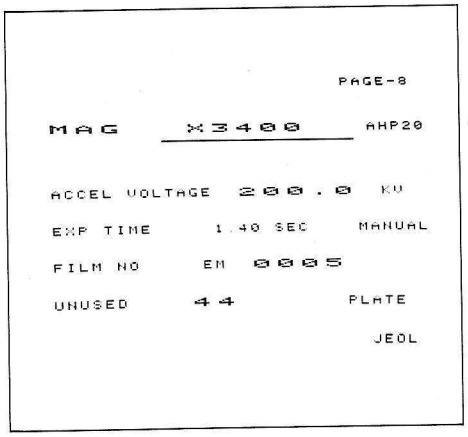
PAGE-6 shows the voltage at each stigmator circuit check point.

1: Condenser lens stigmator coil
2: Objective lens stigmator coil
3: Intermediate lens stigmator coil



A desired character can be written through the keyboard at the position marked with ■. By depressing the ← or → key, the ■ mark can be shifted leftward or rightward, and by depressing the space key, the character in the ■ mark can be erased. Further, by deprssing the RETURN key, the ■ mark can be brought to the first character position on the next line.

If the TEXT key is depressed with characters written on this PAGE, all the characters are erased (the erased characters are not stored in this case), and the ■ mark returns to the initial position. The written characters are stored in the memory by depressing the PAGE key.



1: Same as item 1 on PAGE-1.
2: Same as item 2 on PAGE-1.
3: Same as item 7 on PAGE-1.
4: Same as item 9 on PAGE-1.
5: Same as item 10 on PAGE-1.

5. OPERATION

5. OPERATION

This chapter describes the operation procedures up to and including image recording. Method A covers the startup, image recording, and shutdown procedures, method B the necessary procedure for axis alignment, and method C the procedures for routine observation. It is advisable to become familiar with method A before attempting methods B and C. The symbols L1, L2, R1, R2, GA, GC and KB appearing in parentheses after the names of panel controls designate the respective control panels (see Fig. 3.4-1).

5.1 Emergencies

5.1.1 Power suspension

The microscope automatically shuts down safely. When power is restored, it is necessary to manually restart the microscope.

5.1.2 Cooling water suspension

If water suspension continues for some time, the high-voltage power and lens power supplies are turned off and the vacuum system goes into the protected state. When the supply of cooling water recommences, the microscope must be manually restarted.

5.1.3 Faulty operation

The microscope is fully and automatically protected by safety devices.

5.2 Method A

It is advisable to become familiar with method A before attempting methods B and C. Procedures detailed in this section are skeletonized in the sections on methods B and C.

5.2.1 Startup procedure

1. Make sure that:
   a. The CM button (L1-18) is switched on and the S button (L1-19) is switched off.
   b. The [illegible], LENS POWER SUPPLY, and ACCEL VOLTAGE switches (L2-1, 2, and 3) are set at ON, ON, and OPERATE, respectively.
   c. The GUN AIR and COL AIR button switches (L2-4 and 5) are off.
   d. The compressed air pressure is 0.35 to 0.45 MPa (gage pressure).
   e. The UNATTENDED OPERATION switch on the power supply is set at off.
2. Open the cooling water faucet.
3. Turn on the mains power switch on the distribution board.
4. Insert the key into the POWER switch (L1-3), turn the key to START via ON, keep it at START for five seconds, then release the key (the key returns to ON), and wait for the READY lamp (L1-4) to light up. While waiting, carry out film loading and specimen preparation (Sects. 5.2.2 and 5:2.3).

   Note: As soon as the key of the POWER switch (L1-3) is turned to ON, the PC (printed circuit) boards are checked by the self-diagnostic function, and if any PC boards are found abnormal, their names are displayed on the CRT (R1-14) for about 10 seconds.

5.2.2 Film loading

5.2.2a Loading films into the dispensing magazine

1. Insert an unexposed film into each cassette with the emulsion side facing up under a safelight in a dark room (Fig. 5.2-1).
2. Remove the lid from the dispensing magazine and fully depress the bottom plate until it is clamped.
3. Place the loaded cassettes in the dispensing magazine and replace the magazine lid. Up to 50 cassettes can be loaded in one magazine.

Caution: Do not mistake the dispensing magazine for the receiving magazine (see Fig. 5.2-4). The dispensing magazine is provided with a bottom plate, but the receiving magazine is without it.

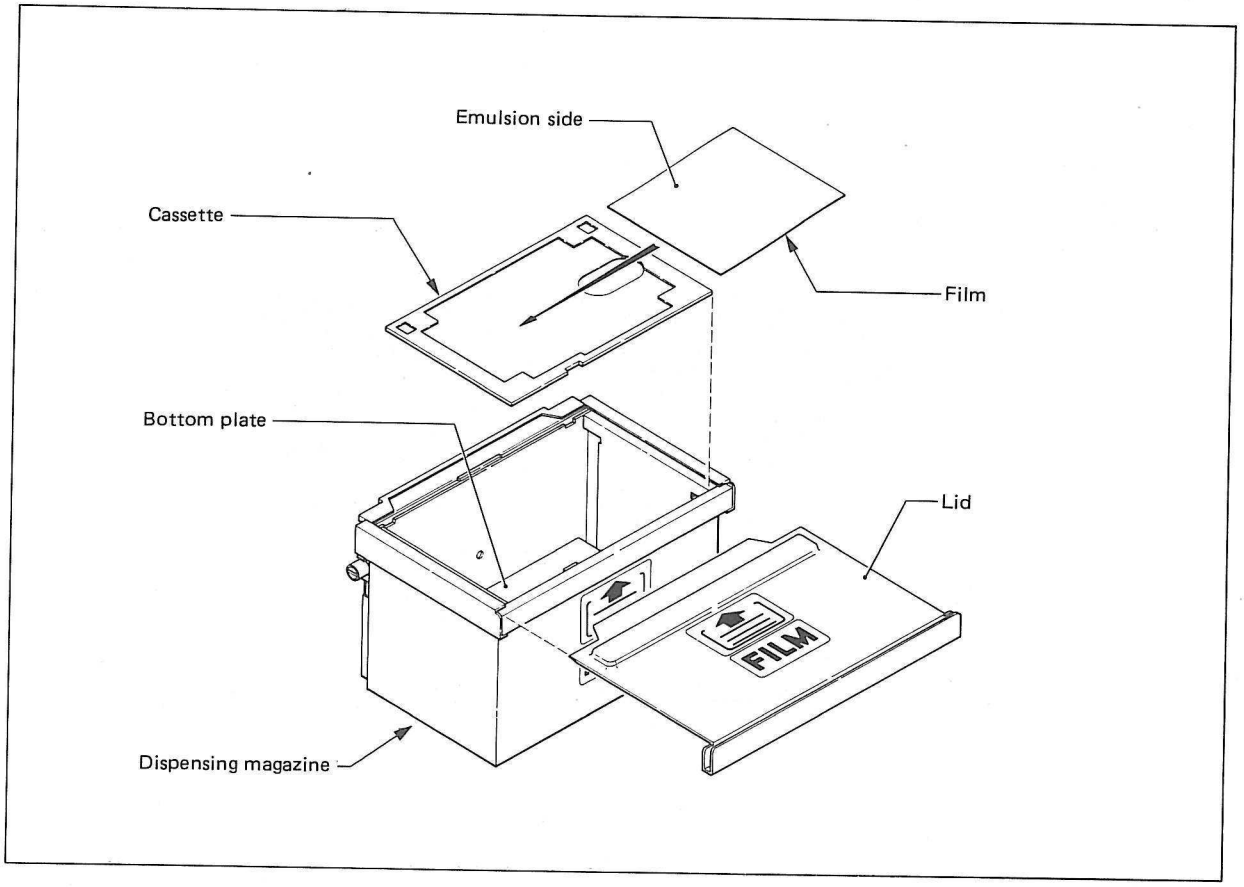


Fig. 5.2-1 Loading films into the dispensing magazine

5.2.2b Inserting (or removing) the magazines into (or from) the camera chamber

1. Make sure there is no unused film in the camera chamber. The number of unused films is indicated after "UNUSED" on PAGE-1 (Fig. 5.2-2) displayed on the CRT (R1-14). That is, if the indicated number is 0, there is no unused film in the camera chamber. If PAGE-1 is not being displayed on the CRT, make the CRT display PAGE-1 in accordance with 5.2.11a.
2. Make sure the FILAMENT knob (L1-2) is set at OFF and the PHOTO button lamp (L1-12) is not lit. If the PHOTO button lamp is on, turn off the FILM ADVANCE AUTO button switch (R1-7) and depress the PHOTO button.
3. Turn the camera chamber door handle clockwise until it stops (Fig. 5.2-3).

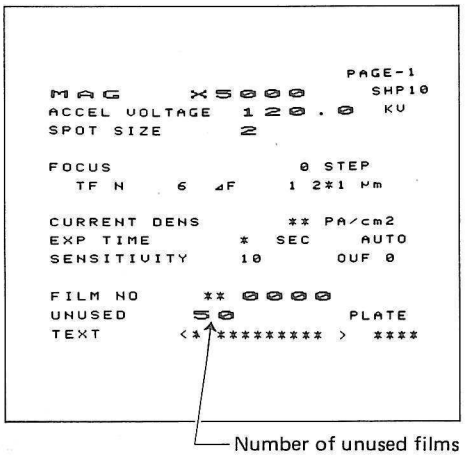


Fig. 5.2-2 PAGE-1

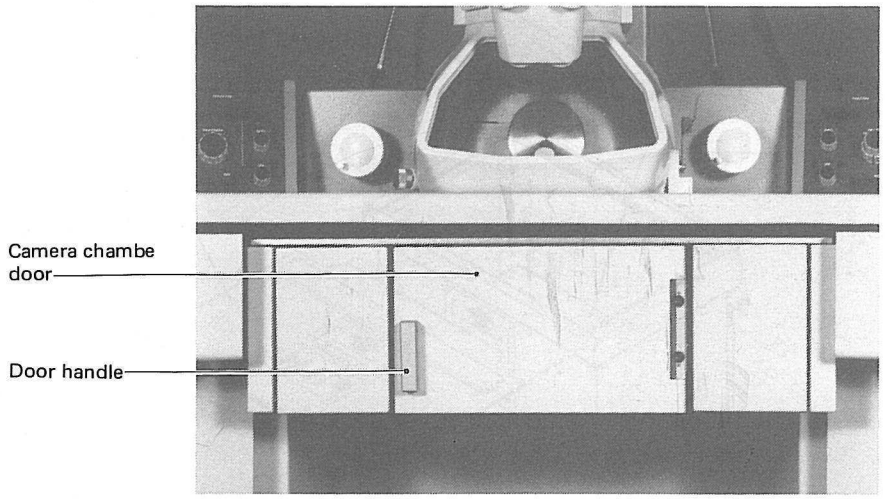


Fig. 5.2-3 Camera chamber

4. Open the camera chamber door.

   Note: Carry out Steps 5 to 9 as quickly as possible so as to avoid exposing the camera chamber to the atmosphere longer than absolutely necessary.

5. Draw out the magazine stand by pulling the handle (Fig. 5.2-4).
6. If there is an empty dispensing magazine in the magazine stand, remove it by lifting it out. Then place the

dispensing magazine loaded with unexposed films squarely in the magazine stand.

Caution: If the magazine is not placed squarely in the magazine stand, it will be impossible to insert the magazine stand smoothly.

Notes: 1. Two dispensing magazines and two receiving magazines (Fig. 5.2-5) are provided in order to enhance throughput. That is to say, while one dispensing magazine is being used, the other can be kept in the desiccator (optionally available) so that the loaded films are ready and de-moisturized when needed. Also, as one receiving magazine is being filled during the course of photography, the second one can be kept handy, ready for the next sequence of filming.

2. When handling the magazines, hold them so as to prevent the magazine lid from dropping out.

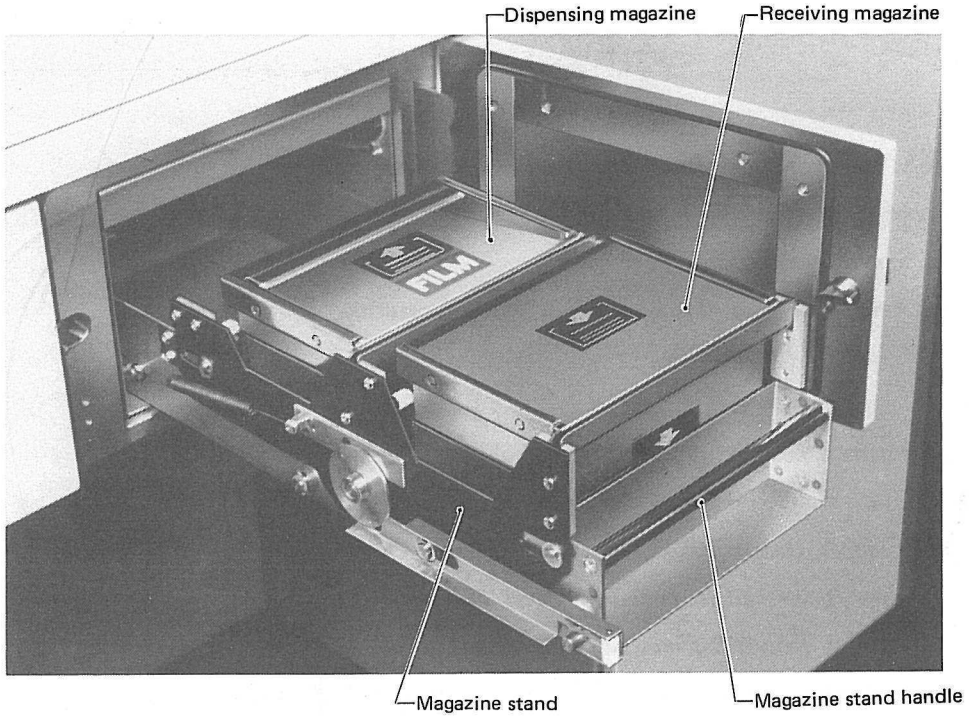
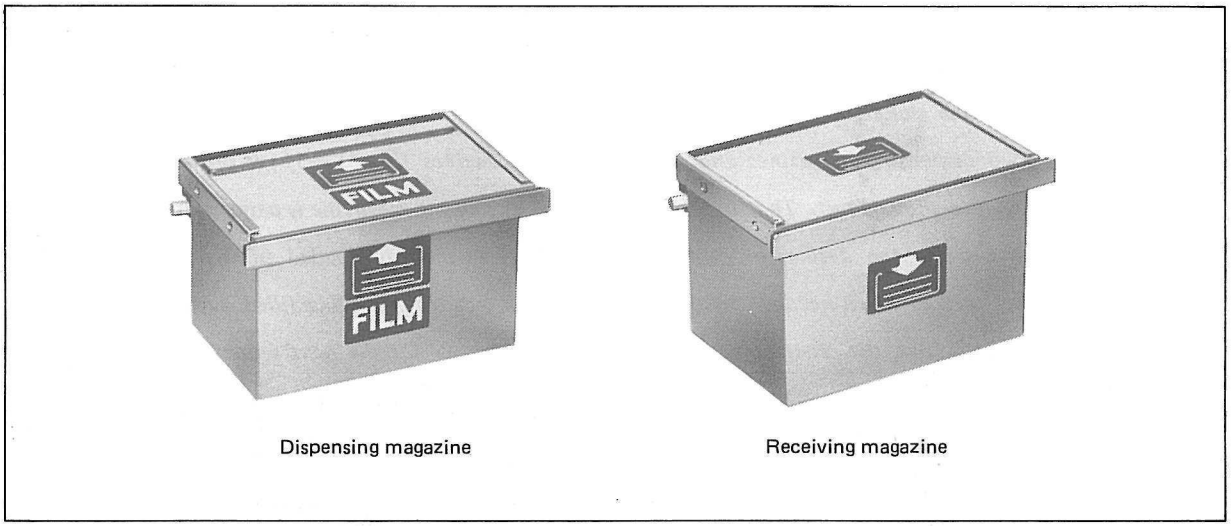


Fig. 5.2-4 Magazine stand



"Fig. 5.2-5 Magazines"

7. If there is a receiving magazine loaded with exposed films in the magazine stand, remove it by lifting it out and replace it with an empty receiving magazine.

   Caution: Never remove the lid from a loaded magazine outside a dark room.

8. Push the magazine stand fully in.
9. Close the camera chamber door and, while holding it closed, turn the door handle counterclockwise as far as it will go.

   Caution: Before closing the camera chamber door, check the O-ring and its contact surfaces for dust, lint, etc. A dirty O-ring may adversely affect the camera chamber vacuum.

10. Write the number of unused films (the number of films loaded in the dispensing magazine) on the CRT.

10a. Let the CRT display PAGE-1 (see Sect. 5.2.11a).

10b. Depress the F NO key (KB-1).

10c. Set the UNUSED number (Fig. 5.2-6) to accord with the number of unused films (see Sect. 5.2.11f).

10d. Depress the C/R key (KB-2).

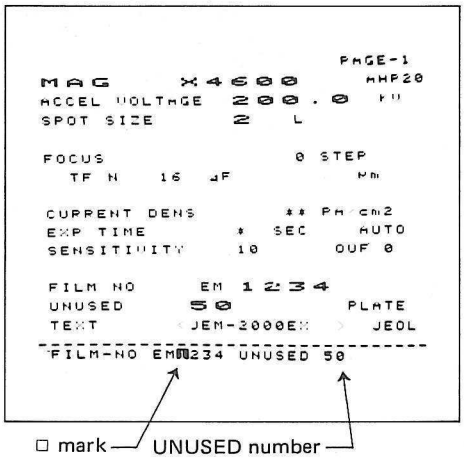


Fig. 5.2-6 Writing the UNUSED number

5.2.3 Specimen preparation

This section describes how to insert the specimen in (and remove it from) the specimen holder.

1. Remove the specimen holder and specimen holder stand from the EM-SQH specimen holder box (Fig. 5.2-7).

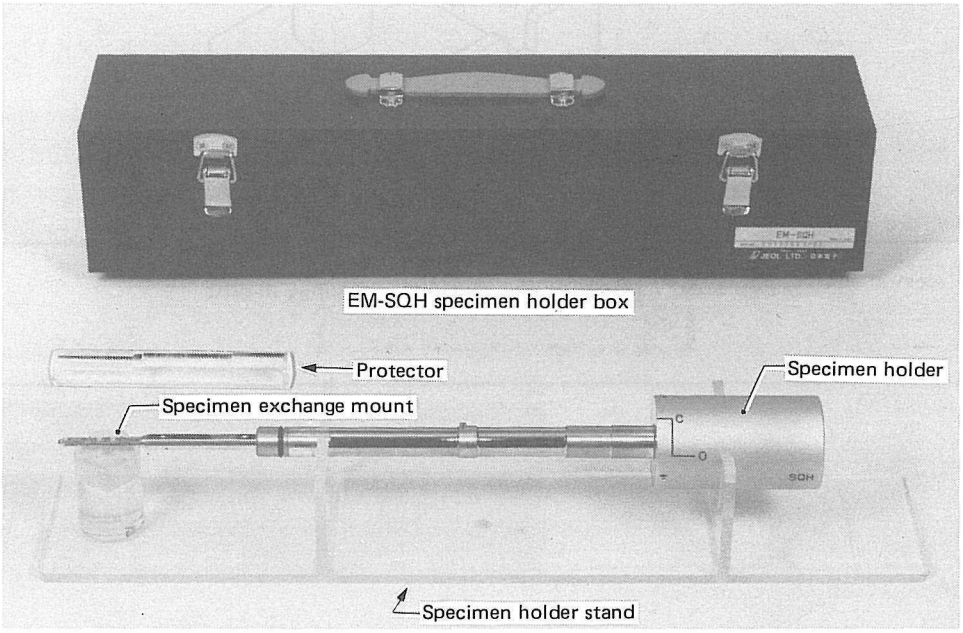


Fig. 5.2-7 EM-SQH specimen holder box and stand

2. Place the specimen exchange mount on the specimen holder stand so that the mount orientates as shown in Fig. 5.2-8.
3. Remove the protector from the specimen holder and place the specimen holder on the specimen holder stand.
4. Raise the specimen clamp by pushing the claw in the direction indicated by the arrow (see Fig. 5.2-9).
5. Insert the specimen and secure it with the clamp by returning the claw to its original position. Make a note of the type and name of the specimen and the holder specimen number inscribed on the holder's side.
6. Cover the specimen holder with the protector and place the specimen holder on the specimen holder stand.

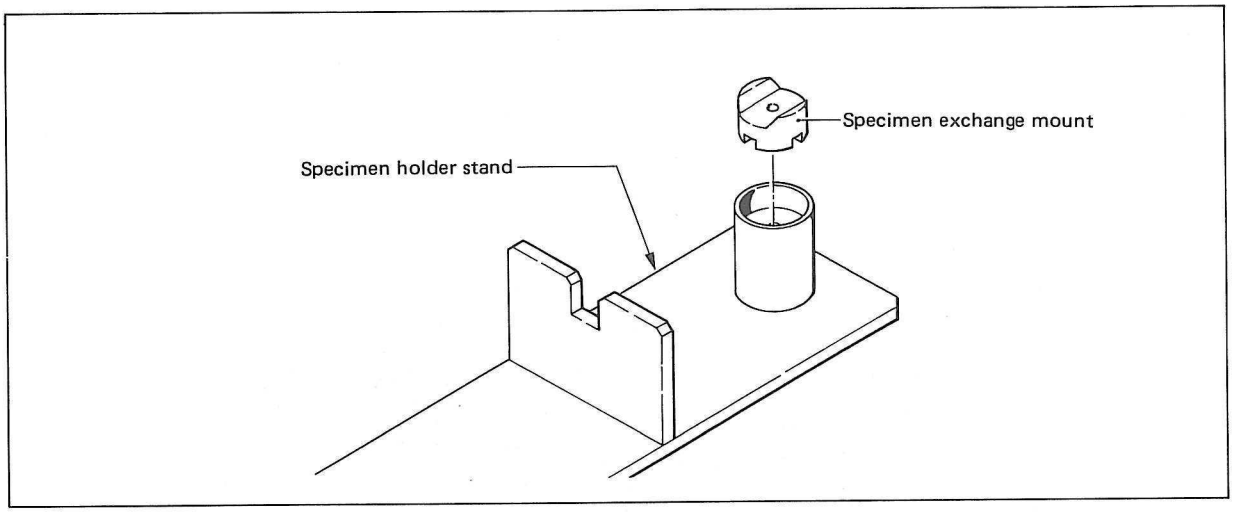


Fig. 5.2-8 Installing the specimen exchange mount

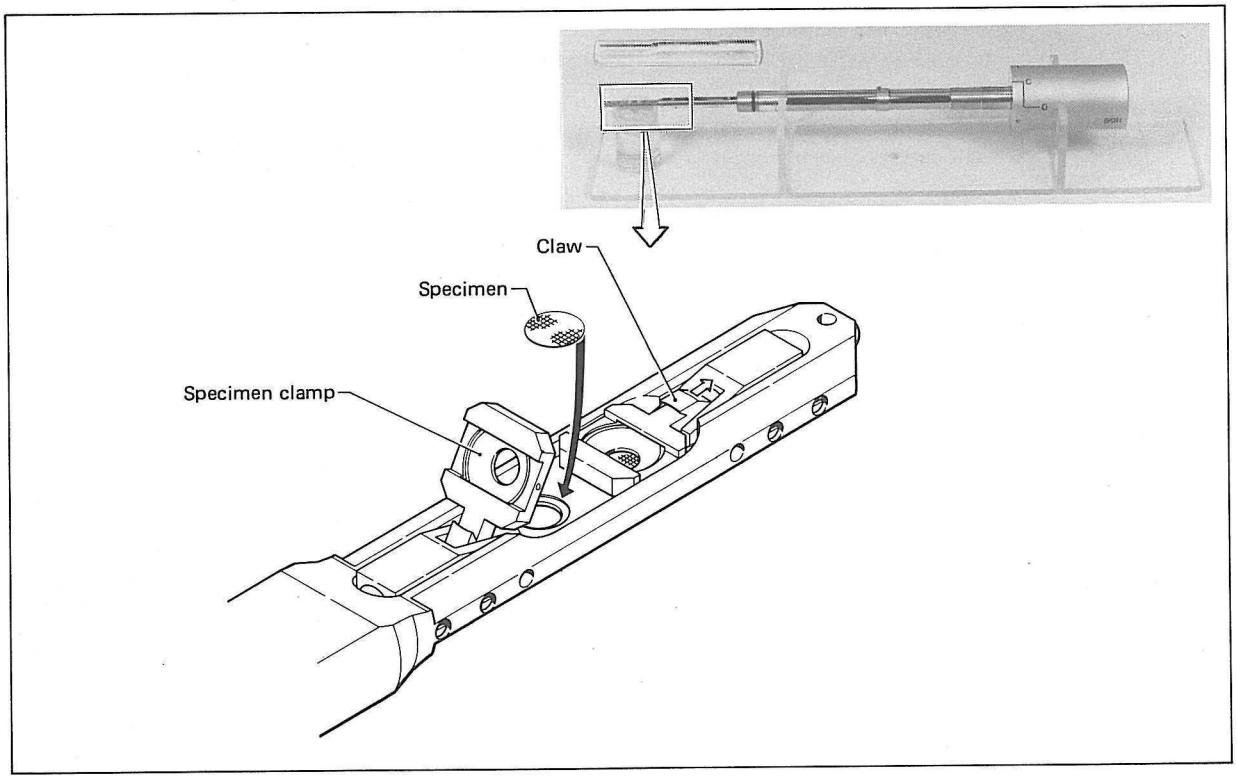


Fig. 5.2-9 Specimen exchange

5.2.4 Electron beam generation

1. Confirm every three months that the reading of the pressure meter on the HT tank is 0.05 or more. If less, replenish the tank with gas (see Subsect. 6.3). Similarly, replenish the gas chamber with gas if the reading of the pressure meter in the window on the central console right cover (Fig. 5.2-10) is less than 1.7 (see Subsect. 6.3).

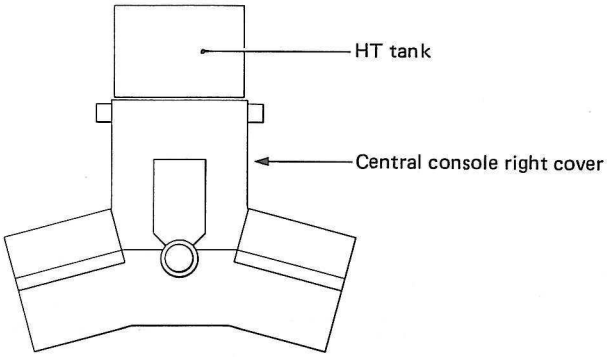


Fig. 5.2-10 Central console right cover

2. Confirm that the READY lamp (L1-4) is lit and the FILAMENT knob (L1-2) is set at OFF.
3. Set the desired accelerating voltage.
   3a. Let the CRT display PAGE-1 (see Sect. 5.2.11a).
   3b. Manipulate the ACCEL VOLTAGE switch (L1-5) so as to obtain the desired ACCEL VOLTAGE value on the CRT.
4. Switch on (built-in lamp lights up) the HT button (L1-6) and confirm that the BEAM CURRENT meter (L1-1) reading (detecting current) becomes stable in the applicable range shown in Table 5.1. If the BEAM CURRENT meter reading does not become stable, carry out Steps 4a ~ 4c as follows.
   4a. Decrease the accelerating voltage to the lowest level and set the FILAMENT knob (L1-2) to the stopper position. The BEAM CURRENT meter reading increases by the beam current value.
   4b. After the BEAM CURRENT meter reading becomes stable, set the FILAMENT knob to OFF, increase the accelerating voltage by 20 kV, and set the FILAMENT knob (L1-2) to the stopper position.
   4c. Repeat Step 4b above until the original accelerating voltage is obtained.

   Note: If the BEAM CURRENT reading becomes excessively high, the supply of high voltage power is automatically turned off and the BEAM CURRENT reading becomes 0. In such case, reduce the accelerating voltage to the next lower value and depress the HT button again.
5. Retract the condenser lens aperture, objective lens aperture, and field limiting aperture from the electron beam path by setting the lever of each aperture assembly (Fig. 5.2-11) to the right side. In the case of condenser lens aperture, set the lever to the right and turn knob 1 fully counterclockwise.

Table 5.1 High voltage and related detecting current values

High voltage (kV)	Detecting current (μA)
80	40 ± 10%
100	50 ± 10%
120	60 ± 10%
160	80 ± 10%
200	100 ± 10%

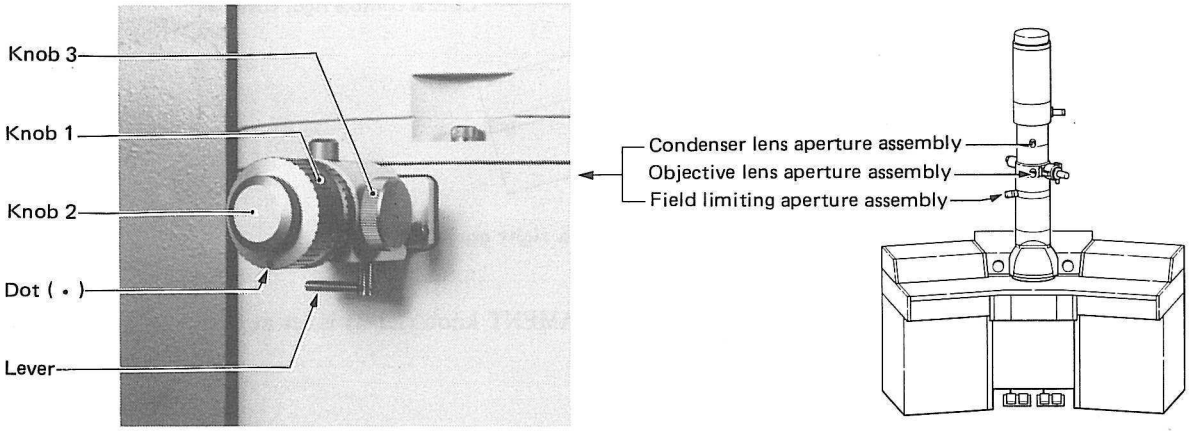


Fig. 5.2-11 Aperture assembly

6. Make sure that the dispensing and receiving magazines are in the camera chamber (see Subsect. 5.2.2b), and the specimen holder is in the "alignment position".

Note: The "alignment position" is the fully turned position in the counterclockwise direction after inserting the holder into the beam path (see Subsect. 5.2.6) and pulling the holder.

Caution: Do not generate any electron beam when the camera chamber is not loaded with two magazines

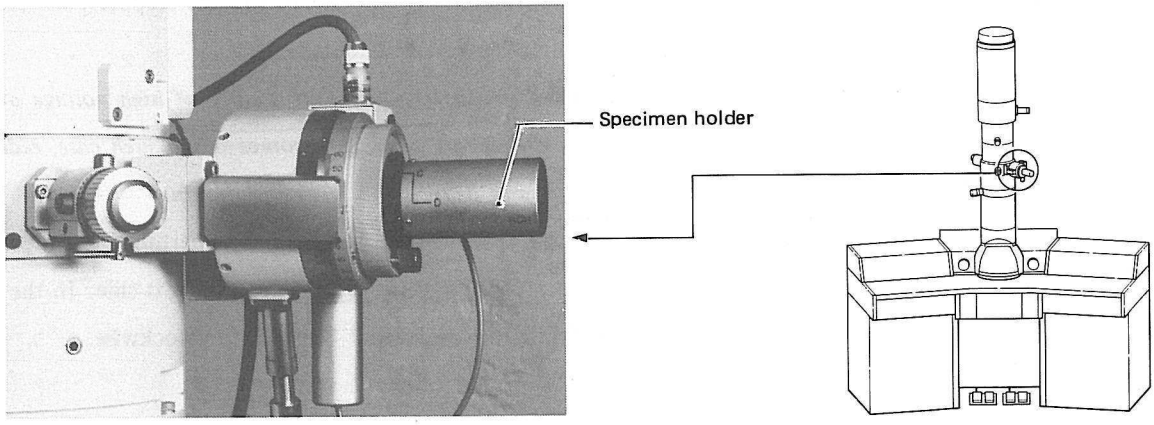


Fig. 5.1-12 Specimen holder installed in the column

7. Let the CRT display PAGE-3 (Fig. 5.2-13) (see Sect. 5.2.11a), and confirm that viewing chamber airlock valve V3 is open. If the large fluorescent screen is raised, lower it by depressing the SCREEN button (R1-11).

   Note: If V3 is closed, the electron beam cannot be generated.

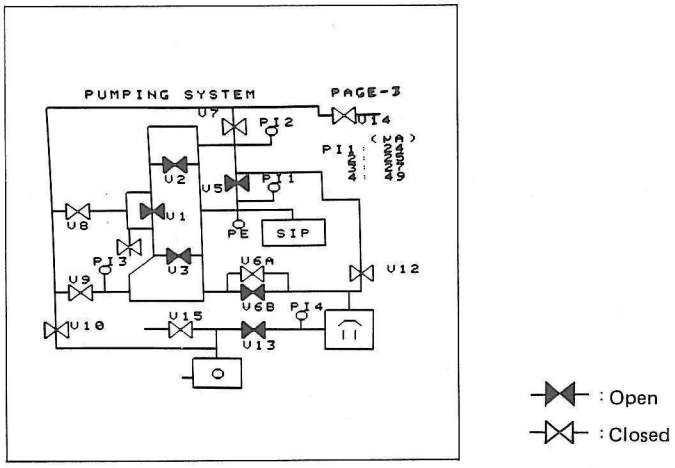


Fig. 5.2-13 PAGE-3

8. After adjusting the BIAS MODE: COARSE and FINE switches (L1-7) so that the BIAS MODE indicator reads 70 to 80, turn the FILAMENT knob (L1-2) clockwise to the stopper while watching the BEAM CURRENT meter (L1-1). If the BEAM CURRENT reading does not change when the FILAMENT knob is turned, electron gun filament breakage is indicated (for details on filament replacement, refer to Sect. 6.1).
9. Darken the room and adjust the control panel illumination with the PANEL LIGHT knob (R1-12).
10. Obtain a spot size of 2.

10a. Let the CRT display PAGE-1 (Fig. 5.2-6; see Sect. 5.2.11a).

10b. Set the SPOT SIZE value on PAGE-1 to 2 with the SPOT SIZE switch (L1-8).

11. Make sure that all the LENS switches (L2-9) are set at ON and depress the MAG2 button (R1-8). The magnification indicated on the MAG line on PAGE-1 is now set at the basic magnification (5,000 times).

    Note: If the basic magnification (the magnification when the MAG2 button is depressed) is not 5,000 times, set it at 5,000 times in accordance with Subsect. 5.2.11q.

12. Turn the BRIGHTNESS knob (L1-14). When the screen is illuminated by the electron beam, proceed to Step 18. If the fluorescent screen is not illuminated, carry out the following steps.

    Note: The BRIGHTNESS knob turns endlessly. If this knob is excessively turned, however, weak peep sounds will be heard.

13. Set the SHIFT: X and Y knobs (L1-16, R1-1) to the midway position, release the PROJ button switch (L2-9), and turn the BRIGHTNESS knob (L1-14). If no illumination is observed on the screen, proceed to Step 14. When illumination appears on the screen, manipulate the SHIFT: X and Y knobs and BRIGHTNESS knob for brighter illumination; then depress the PROJ button switch and achieve brightest illumination with the above-mentioned knobs. Then proceed to Step 18.

    Note: When the SHIFT: X and Y knobs (L1-16, R1-1) are set to the midway position, the left and right directional indicator lamps above each knob light up.

14. Set the GUN ALIGN: SHIFT: X, Y and TILT X, Y knobs (GA-1, 2) to their midway positions, turn on the GUN SCAN button switch (L2-8), and then manipulate the BRIGHTNESS knob (L1-14) so that the fluorescent screen is illuminated by the electron beam.

    Note: The GUN ALIGN: SHIFT: X, Y and TILT X, Y knobs are of the multi-turn type.

15. Manipulate the GUN ALIGN: SHIFT: Y and TILT: Y knobs (GA-1, 2) and the BRIGHTNESS knob (L1-14) so as to obtain the brightest illumination at the screen center.
16. Release the GUN SCAN button (L2-8).
17. Manipulate the GUN ALIGN: SHIFT: X and TILT: X knobs (GA-1, 2) and the BRIGHTNESS knob (L1-14) so as to obtain the brightest illumination. If the illumination becomes glary in the course of this operation, stop manipulating the knobs, depress the PROJ button (L2-9) and manipulate the knobs again so as to obtain the brightest illumination.

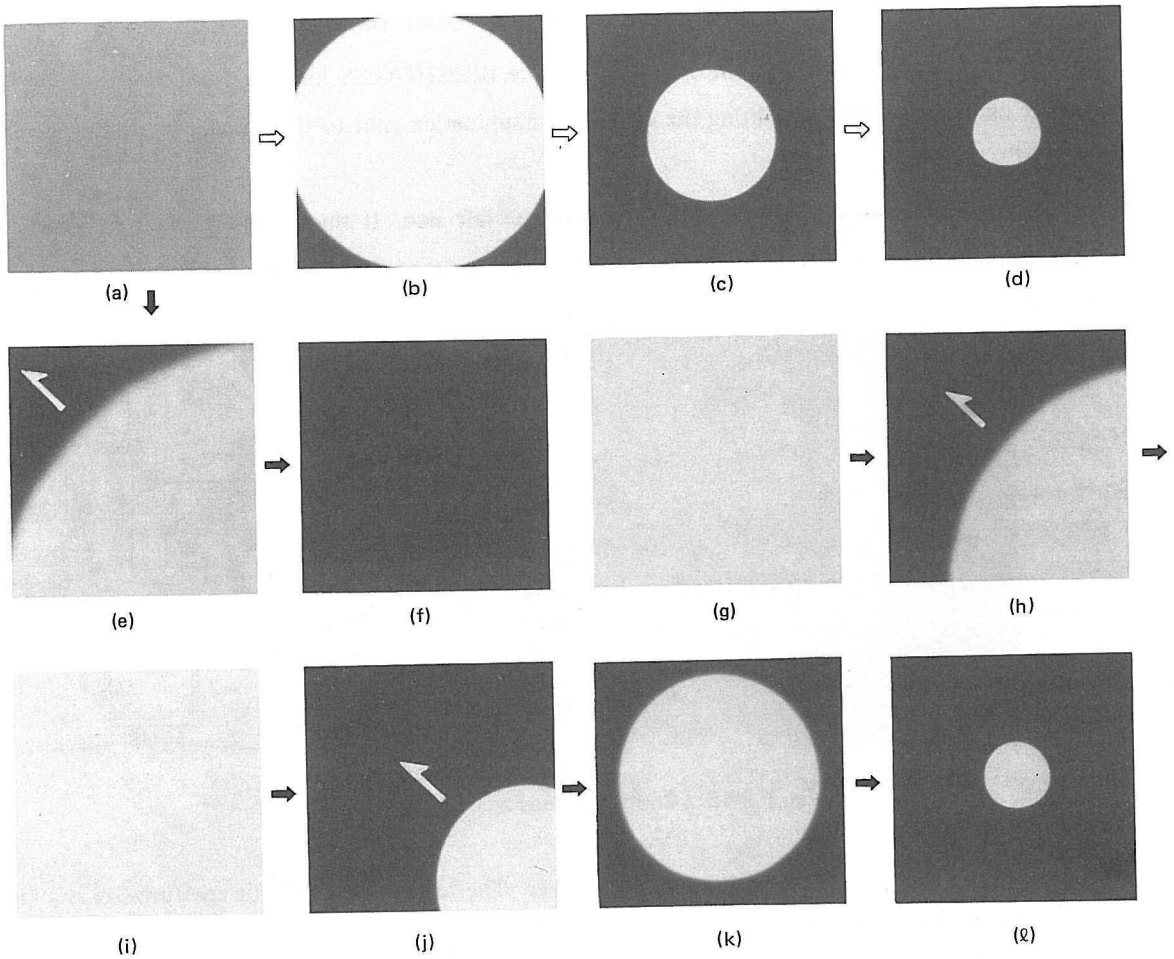
    Caution: Do not allow the illumination to become too bright with the PROJ button switch (L2-9) off; otherwise the fluorescent screen material may be damaged by excessive electron bombardment.

18. Converge the electron beam with the BRIGHTNESS knob (L1-14) (see Fig. 5.2-14).

    If the illumination becomes circular and the illumination spot converges on the screen as shown by a to b, c and d in Fig. 5.2-14 (and then expands), insert the condenser lens aperture in accordance with Sect. 5.2.5.

    If the illumination shifts off the screen as shown by a to e and f, proceed as follows:

    Eliminate the shadow by shifting the illumination in the direction of the arrow (e) with the SHIFT knobs (L1-16, R1-1) and then reconverge the electron beam with the BRIGHTNESS knob (L1-14) as shown by e to g and h. Repeat this shift and convergence procedure (h to i and j) until the illumination spot converges on the screen as shown by j to k and ℓ.



a ⇨ b ⇨ c ⇨ d : Correctly aligned

a ➡ e ➡ f or a ➡ i ➡ j : Incorrectly aligned

e ➡ g ➡ h ➡ i ➡ j ➡ k ➡ ℓ : Alignment procedure

Fig. 5.2-14 Condenser lens alignment

5.2.5 Inserting the condenser lens aperture into the beam path

1. Set the magnification to 5,000 times, manipulate the BRIGHTNESS knob (L1-14) so as to obtain the smallest illumination spot, and bring the converged illumination spot to the screen center with the SHIFT knobs (L1-16, R1-1).
2. Set the condenser lens aperture assembly lever to the left side. If this causes the illumination spot to disappear, manipulate knobs 2 and 3 so as to reproduce the spot (Fig. 5.2-15).

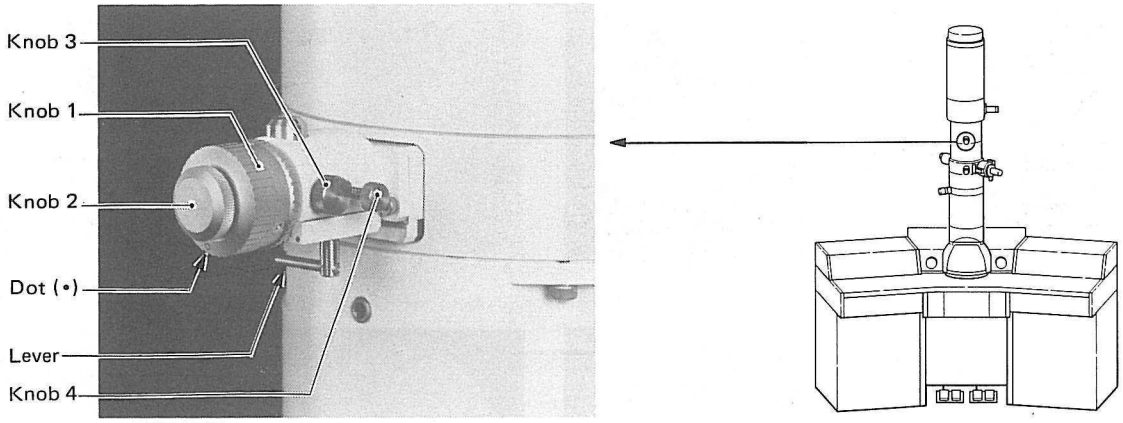
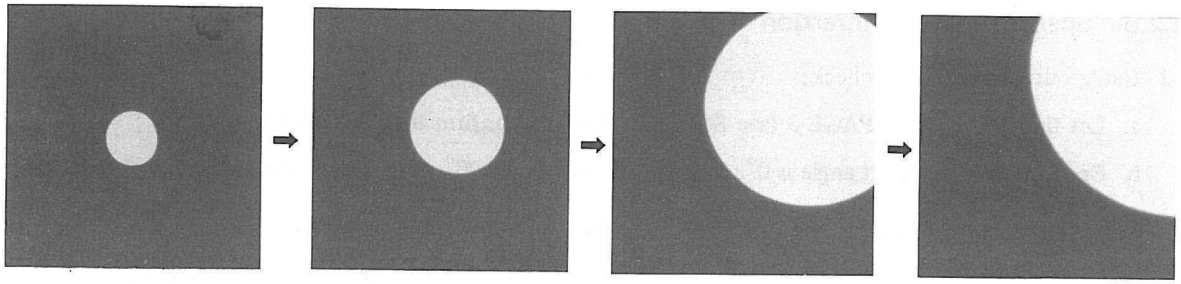


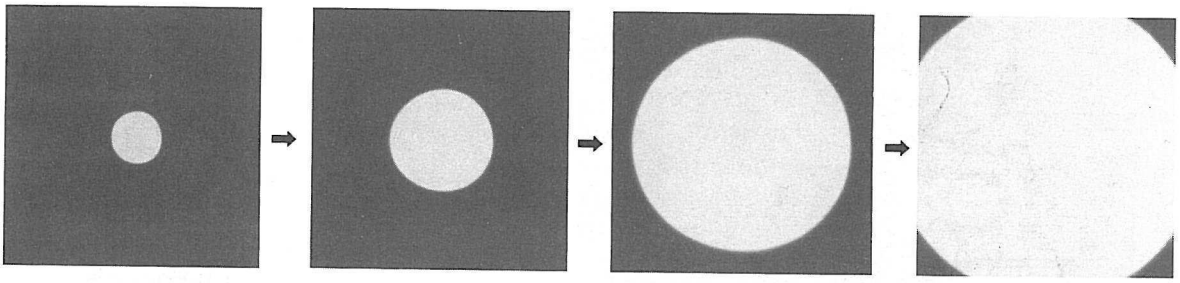
Fig. 5.2-15 Condenser lens aperture assembly

3. Select the desired aperture size with knob 1 and lever. The relation between the aperture size and knob 1 and lever is described in Subsect. 4.1.

   Note: Decreasing the aperture size improves the image quality, but darkens the image.
4. Gradually turn the BRIGHTNESS knob (L1-14) clockwise. If the illumination spot center deviates from the screen center (Fig. 5.2-16a), return the spot to the screen center by manipulating knobs 2 and 3.
5. Manipulate knobs 2 and 3 when the lever is set to the left, or knobs 2 and 4 when the lever is set to the right, so that the illumination spot concentrically converges on and spreads from the screen center (Fig. 5.2-16b) when the BRIGHTNESS knob (L1-14) is turned clockwise and counterclockwise around the position for the smallest illumination spot.



a: Incorrectly aligned



b: Correctly aligned

Fig. 5.2-16 Condenser lens aperture alignment

5.2.6 Specimen holder insertion

1. Carry out the following check:

   1a. Let the CRT display PAGE-3 (see Sect. 5.2.11a) and confirm that valve V7 is closed.

   1b. Confirm that the X-tilt angle is 0°. If the X-tilt angle is not 0°, zero it with the applicable X pedal switch (Fig. 5.2-17).

   Note: The X-tilt speed can be varied with the X-TILT knob (GC-1).

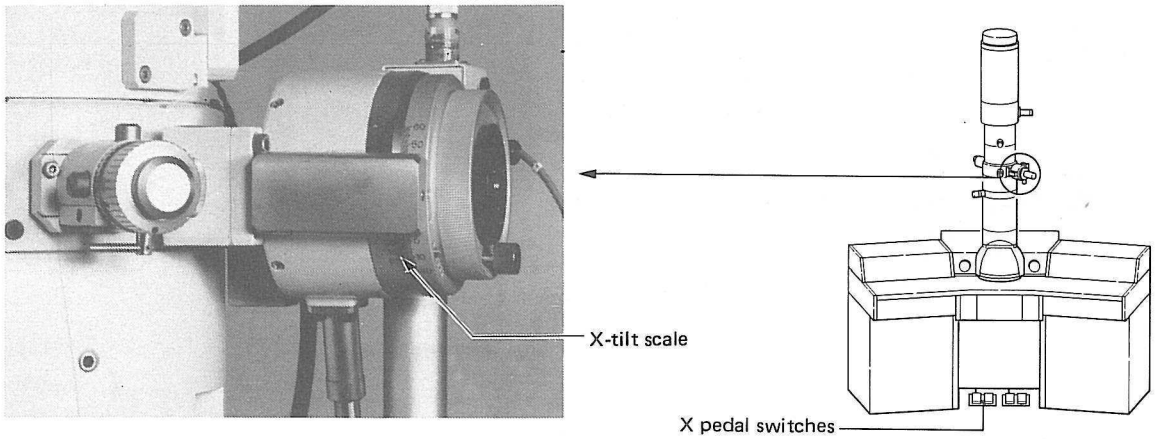


Fig. 5.2-17 X-tilt scale

2. Set the two X-tilt angle limiting screws (Fig. 5.2-18) to 30°.

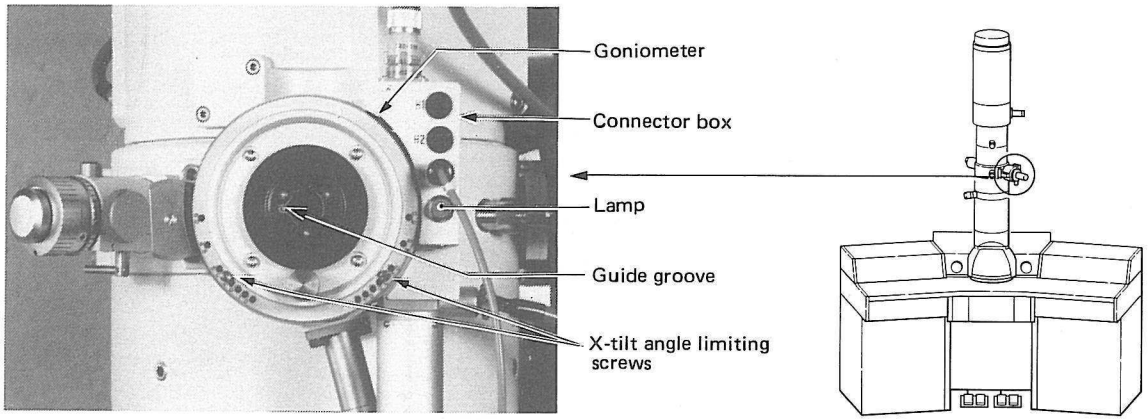


Fig. 5.2-18 Goniometer

3. Remove the protector from the EM-SQH specimen holder loaded with a specimen (see Sect. 5.2.3) and confirm that there is no dirt or lint on the O-ring of the specimen holder.

4. After setting the FILAMENT knob (L1-2) to OFF, match the guide pin of the specimen holder with the guide groove of the goniometer (Fig. 5.2-18), insert the holder into the goniometer until it stops, and wait until the connector box lamp lights up with the holder pushed against the goniometer. Then release your hold, and evacuation of the goniometer starts.

   Note: If valves V2 and V3 are closed and/or the reading of PiG4 is approximately over 150μA with valve V13 open, the connector box lamp does not light up. In such case, wait until valves V2 and V3 open and/or the reading of PiG4 becomes approximately below 150μA. The vacuum system diagram is displayed on PAGE-3 on the CRT.

5. When the connector box lamp goes out (goniometer evacuation is completed), turn the specimen holder clockwise and push it in all the way.
6. Turn the FILAMENT knob (L1-2) to the stopper position.
7. Set the specimen number indicator to the desired specimen number (see Step 5, Sect. 5.2.3) with the specimen selector.

   7a. Let the CRT display PAGE-1 (see Sect. 5.2.11a).

   7b. Depress the LOW MAG button (R1-8) and set the L MAG value on the CRT to 50 to 80 with the SELECTOR switch (R1-9).

   7c. Display PAGE-2 on the CRT (Subsect. 5.2.11) and set the P-Y value on the CRT to 0 with the right specimen shifting knob.

   7d. Spread the electron beam with the BRIGHTNESS knob (L1-14) so that the field of view is entirely covered by the electron beam.

   7e. Set the P-X value on the CRT to +1000 with the left specimen shifting knob.

   7f. Set the specimen number indicator from 1 to 2 and bring the upper right edge of the selected specimen field to the screen center (Fig. 5.2-20) with the specimen selector (Fig. 5.2-19).

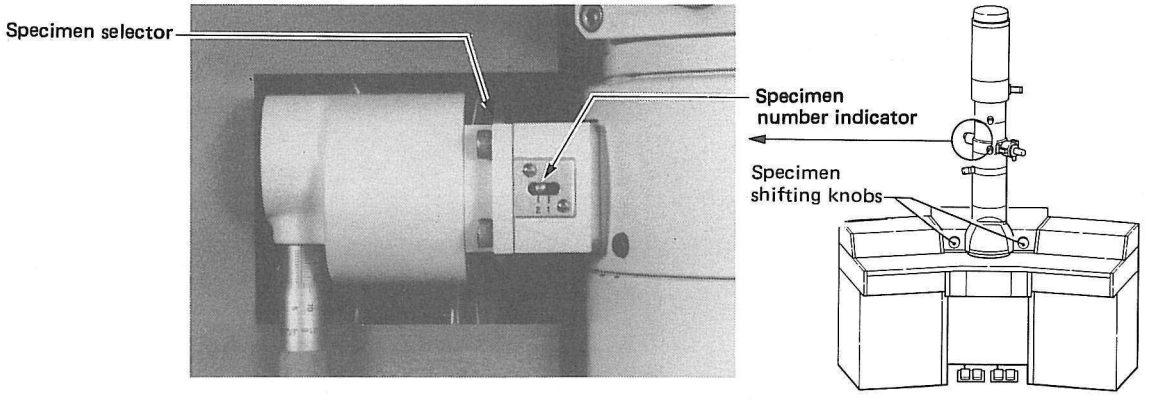


Fig. 5.2-19 Specimen selecting device

8. Select the desired field of view with the left and right specimen shifting knobs.

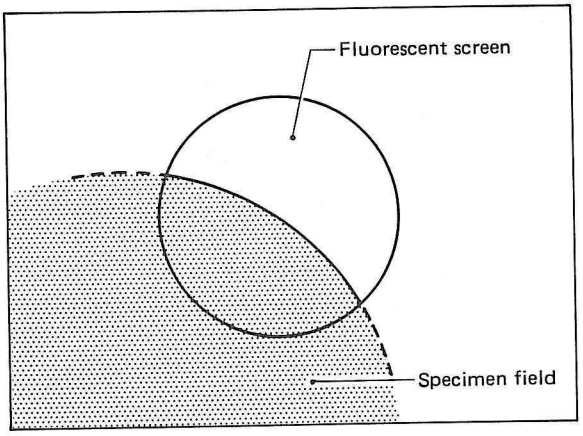


Fig. 5.2-20 Adjusting the field of view

9. Raise the magnification with the SELECTOR switch (R1-9). If this causes the image to darken, adjust the image brightness with the BRIGHTNESS knob (L1-14) and if this causes the selected field of view to shift from the screen center, adjust the field of view with the specimen shifting knobs. When the maximum magnification is obtained, depress the MAG 2 button (R1-8).
10. To remove the specimen holder, proceed as follows:
    10a. Set the FILAMENT knob (L1-2) to OFF.
    10b. Pull the specimen holder, turn it counterclockwise, and draw it out.
    10c. Cover the specimen holder with the protector and place the holder in the specimen holder box.

5.2.7 Inserting the objective lens aperture into the beam path

1. After confirming that the specimen is inserted in the beam path, depress the DIFF button (R1-8). Keep the electron beam sufficiently spread with the BRIGHTNESS knob (L1-14).
2. Obtain a caustic spot (zero magnification spot) with the DIFF FOCUS knob (R1-10) as shown in Fig. 5.2-21. If the caustic spot is off the screen center, center the spot with the PROJ ALIGN: X and Y knobs (R2-3).

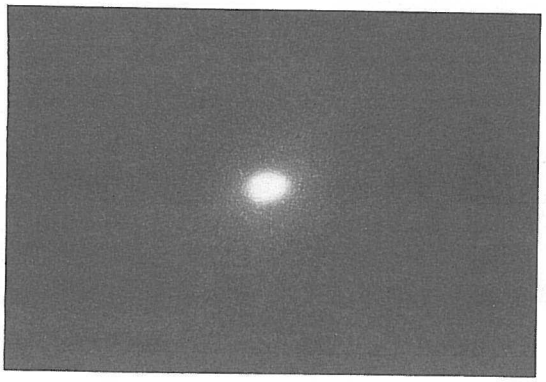


Fig. 5.2-21 Caustic spot

3. Obtain the smallest illumination spot with the BRIGHTNESS knob (L1-14) and make the illumination spot center coincide with the caustic spot center by manipulating the SHIFT knobs (L1-16, R1-1).
4. Set the objective lens aperture assembly lever to the left side (Fig. 5.2-22).

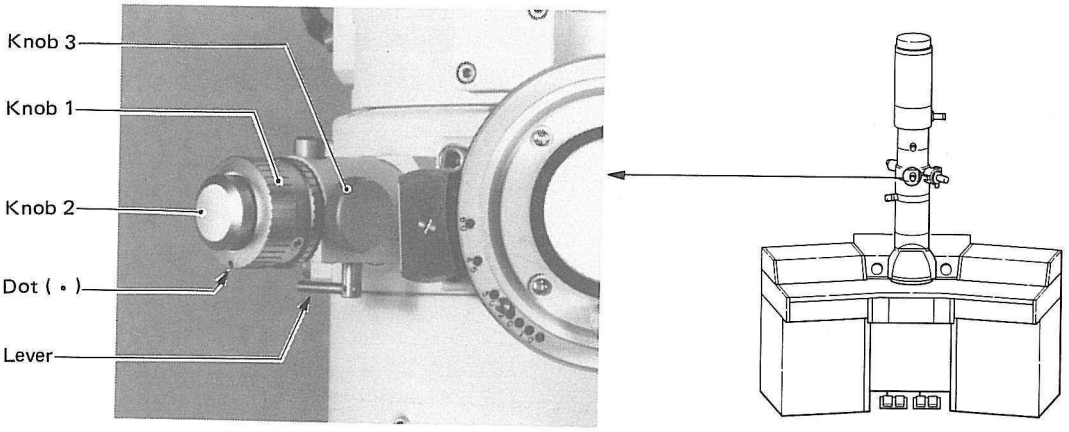


Fig. 5.2-22 Objective lens aperture assembly

5. Select the desired aperture size with knob 1 (see Subsect. 4-1).

   Note: Decreasing the aperture size improves the image quality, but darkens the image.

6. Focus the aperture image (shadow) with the DIFF FOCUS knob (R1-10).
7. Manipulate knobs 2 and 3 so that the caustic spot lies in the center of the aperture hole image as shown in Fig. 5.2-23.

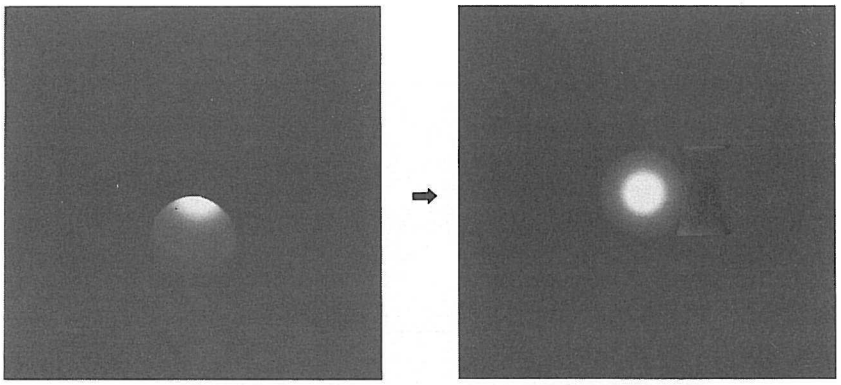


Fig. 5.2-23 Objective lens aperture alignment

8. Depress the MAG2 button (R1-8).

5.2.8 Image observation

1. After confirming that the MAG2 button (R1-8) is depressed, obtain the smallest illumination spot with the BRIGHTNESS knob (L1-14), and bring the spot to the screen center with the SHIFT knobs (L1-16, R1-1).
2. Depress the IMAGE X (or Y) button (R1-4). If the illumination spot appears as a double spot or divides into two spots, adjust the IW ADJ: X (or Y) knobs (R2-2) so as to obtain a single illumination spot.
3. Spread the illumination spot with the BRIGHTNESS knob (L1-14). If the image is doubled, adjust the OBJ FOCUS knobs (R1-3) so as to obtain a single stationary image. Then, release the IMAGE X (or Y) button (R1-4).

   Note: When the OBJ 16X button switch (R1-3) is on, the objective lens current variable range per one notch of the OBJ FOCUS knob enlarges 16 times.
4. Select the desired field of view with the left and right specimen shifting knobs.

   Note: The selected field of view is indicated by the ■ mark on PAGE-2 on the CRT (see Sect. 5.2.11a).
5. Let the CRT display PAGE-1 and confirm that the name of the objective lens pole piece being used is displayed on PAGE-1. If the displayed name is different from that of the pole piece being used, carry out Subsect. 5.2.11e.

   Caution: If the objective lens pole piece name displayed on PAGE-1 is different from the name of the pole piece being used, the correct magnification is not displayed.

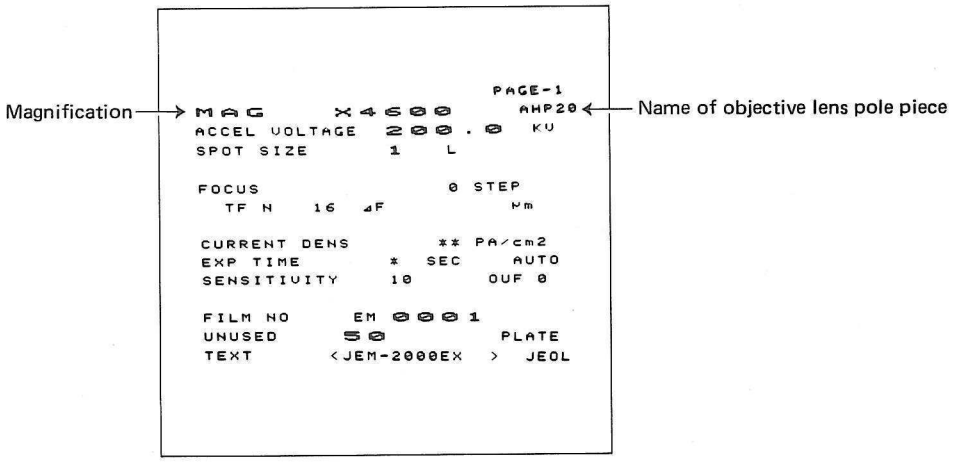


Fig. 5.2-24 PAGE-1

6. Select the desired magnification with the SELECTOR switch (R1-9) (a suitable magnification: less than 50,000X) and adjust the image brightness with the BRIGHTNESS knob (L1-14). If the illumination spot

center does not coincide with the screen center, center the illumination spot with the SHIFT knobs (L1-16, R1-1).

Note: If a magnification is selected with the MAG2 button (R1-8) depressed, the selected magnification is not stored in the memory. However, if a magnification is selected with the MAG1 button (R1-8) depressed, the selected magnification is stored in the memory. That is to say, the magnification is automatically set to the stored value by depressing the MAG1 button. On the other hand, by depressing the MAG2 button, the magnification is always set to the basic magnificlation (Subsect. 5.2.11q).

7. Depress the IMAGE X (or Y) button (R1-4). If the image appears as a double image, adjust the OBJ FOCUS knobs (R1-3) so as to obtain a single stationary image (focusing using the image wobbler). Then release the depressed button.

5.2.9 Image recording by automatic exposure

1. Turn on the SHUTTER AUTO button switch (R1-6) and turn off the FILM ADVANCE AUTO button switch (R1-7).
2. Bring the field of view to be photographed into the frame ([ ]) on the fluorescent screen with the left and right specimen shifting knobs as shown in Fig. 5.2-25.

   Note: A large frame and a small frame are drawn on the fluorescent screen. The large frame is used for photography using special films.

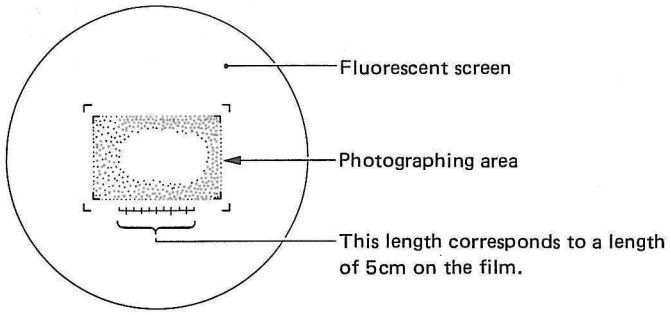


Fig. 5.2-25 Photographing area

3. If the position of the field of view is to be stored, carry out the steps in Sect. 5.2.11i.
4. Write the information to be recorded on the film on PAGE-1. 2 characters can be written on the FILM NO line and 17 characters on the TEXT line (Fig. 5.2-26). See Sects. 5.2.11g and j for details.

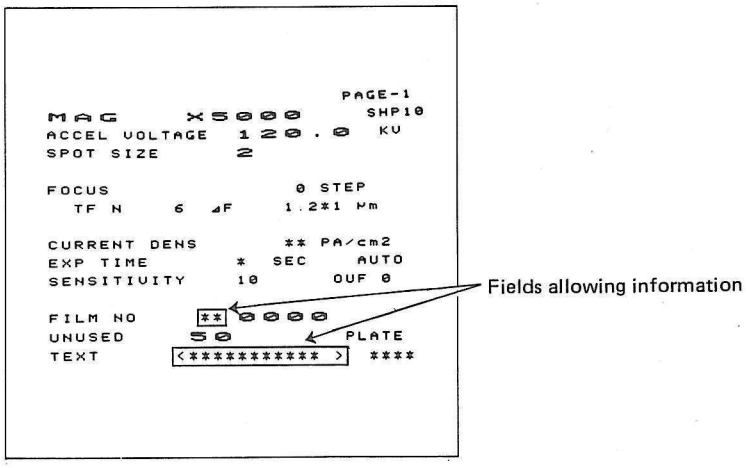


Fig. 5.2-26 Fields allowing information to be written

5. Focus the image.

5a. Push the fluorescent screen lever (Fig. 5.2-27) until it stops. The small fluorescent screen is now inserted into the beam path.

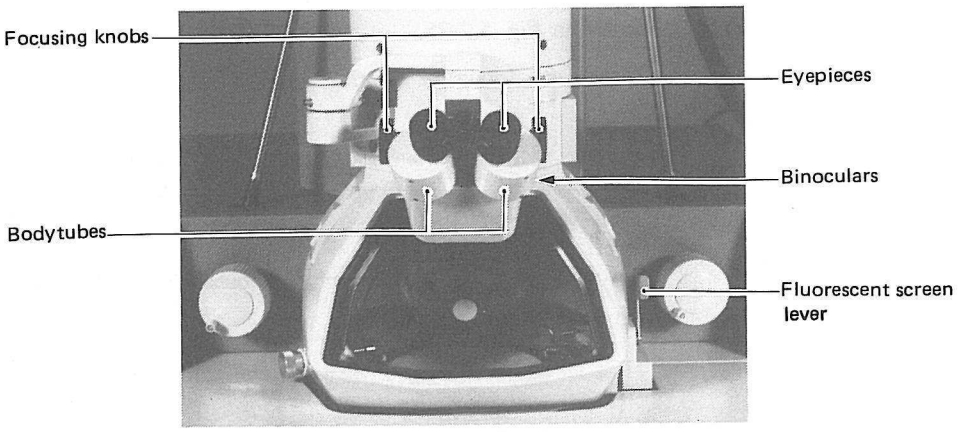


Fig. 5.2-27 Binoculars

5b. Focus the binoculars on the small fluorescent screen.

Note: First, focus the whole binoculars with the focusing knobs, and adjust, if necessary, the inter-ocular distance by changing the distance between the bodytubes, and focus the eyepieces by turning the knurled ring (Fig. 5.2-27).

5c. Obtain the OUF mode (Subsect. 5.2.11o)

Note: By using this mode in conjunction with the image wobbler, an optimum underfocus image can be easily obtained. The amount of underfocus can be varied by keyboard operation (see Sect. 5.2.11o).

5d. Depress the IMAGE X (or Y) button (R1-4). If the illumination spot oscillates or divides into two spots, adjust the IW ADJ: X (or Y) knobs (R2-2) so as to obtain a single stable illumination spot.

5e. Observe an image with clear contours on the small fluorescent screen through the binoculars. If the image appears as a double image, adjust the OBJ FOCUS knobs (R1-3) so as to obtain a single stationary image. If the image is underfocused or overfocused, it will appear as a double image as shown in Fig. 5.2-28.

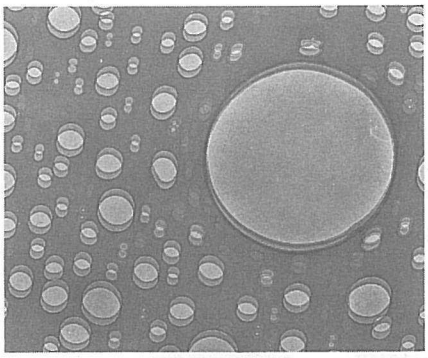
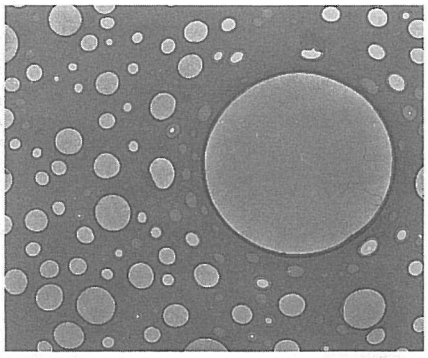
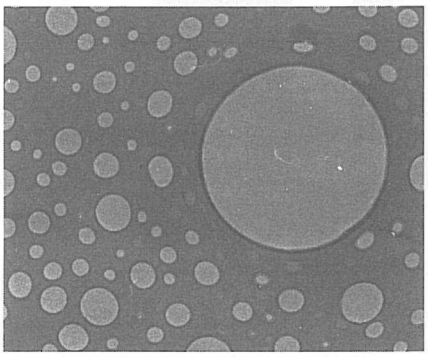
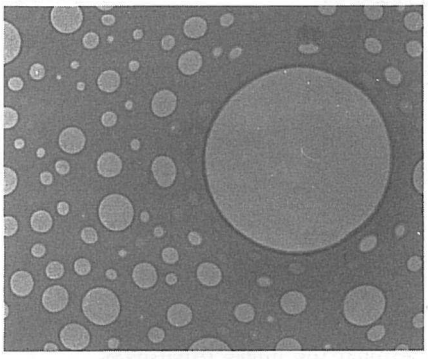
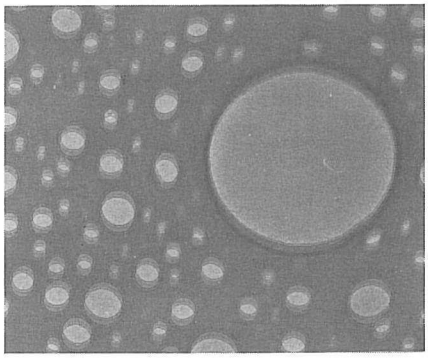
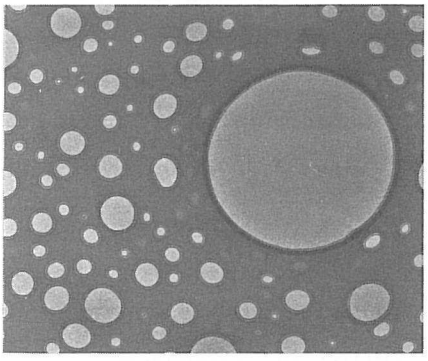
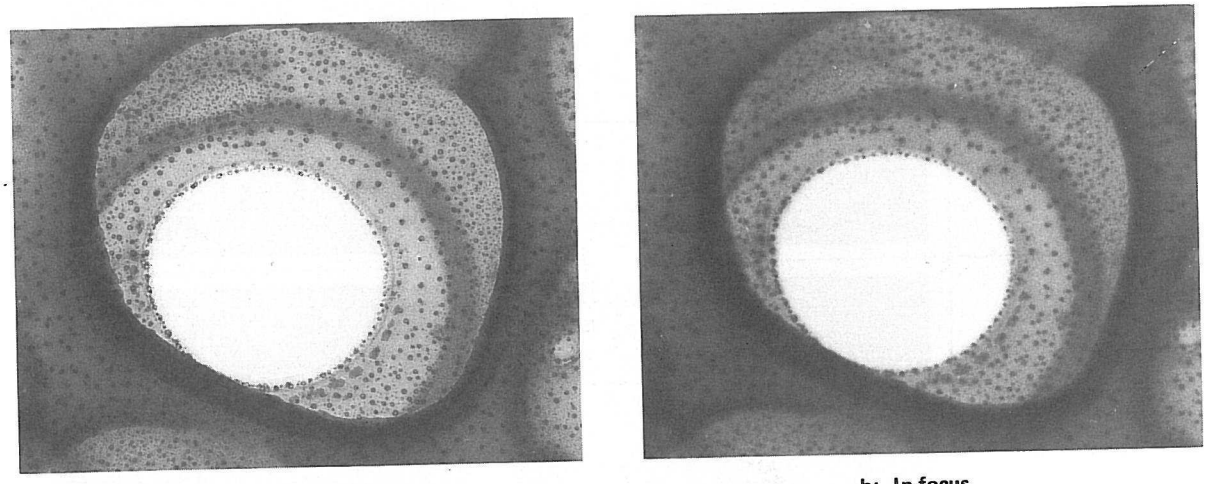
	IMAGE X button switch	
	ON	OFF
Underfocus		
In-focus		
Overfocus		

Fig. 5.2-28 Focusing with the image wobbler

5f. Release the IMAGE X (or Y) button switch (R1-4).

In this state (with the IMAGE X (or Y) button switch (R1-4) on after focusing in the OUF mode with the IMAGE X (or Y) button switch off), an optimum underfocus image can be photographed (Fig. 5.2-29).



a: Optimum underfocus

b: In-focus

Fig. 5-2-29 Optimum underfocus

6. Adjust the image brightness.

6a. Let the CRT display PAGE-1.

6b. Adjust the BRIGHTNESS knob (L1-14) so that the exposure time displayed on the EXP TIME line becomes the desired value (usually 2 to 4 sec).

Note: If the relation between the brightness and the exposure time is to be changed, carry out the steps in Sect. 5.2.11 ℓ.

7. Depress the PHOTO button (L1-12) with the small screen in the beam path, and after the built-in lamp of the button lights up, depress the PHOTO button again. If the built-in lamp is already on, depress the PHOTO button only once.

Notes: 1. The EXP lamp (L1-13) lights up and remains lit while the shutter is open. The built-in lamp of the PHOTO button (L1-12) goes out when the exposed film is advanced from the exposing position.

2. The PHOTO button lamp does not light when all loaded films have been exposed.

3. When the large screen is entirely illuminated, the small screen may be retracted from the beam path.

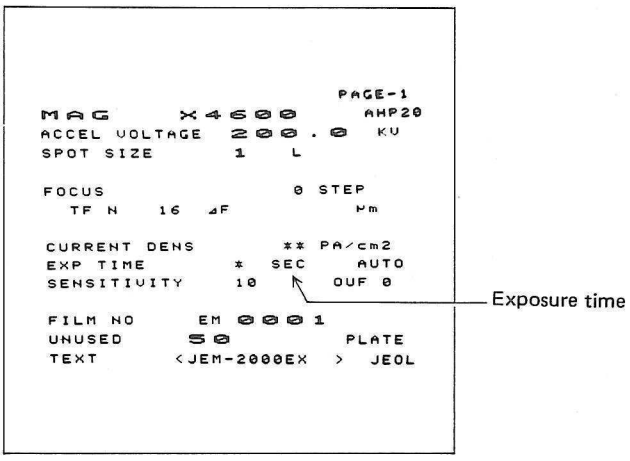


Fig. 5.2-30 Exposure time

5.2.10 Film processing

1. Unload the receiving magazine from the camera chamber (see Sect. 5.2.2b).
2. Adjourn to a darkroom and remove the lid from the receiving magazine and the cassettes from the magazine under a safelight (red lamp).
3. Carefully remove the film from the cassette (Fig. 5.2-31).

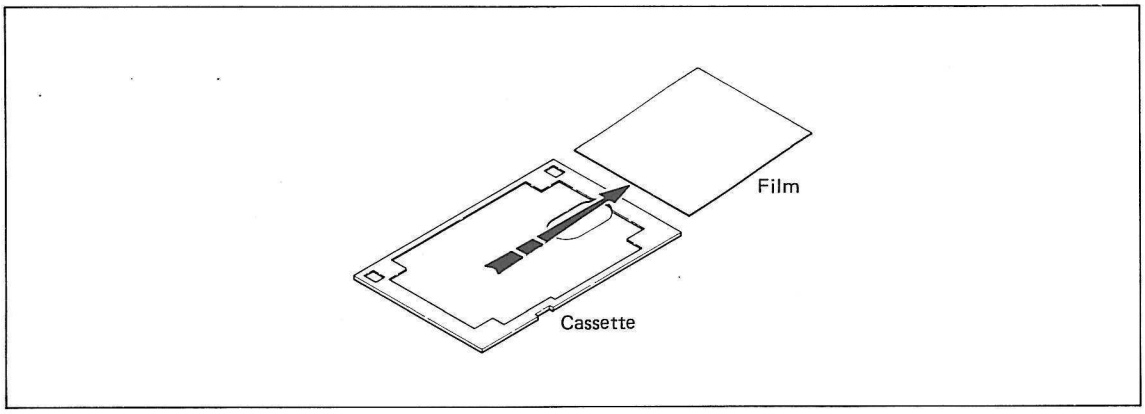


Fig. 5.2-31 Removing the film from the cassette

4. Immerse the film in a developer (20 ± 0.5°C), and leave it in until the exposed latent image becomes sufficiently visible (usually three or four minutes; Fig. 5.2-32).
   During the developing process, agitate the developer or move the film in order to avoid developing marks.
   Note: If only a few films are to be processed, developing trays may be used. However, if many films are to be processed at one time, it is recommended to use suitable tanks and hangers (stainless steel tanks, polyvinyl chloride tanks, etc. are the best).
5. Immerse the film in a stop bath (2 to 3% glacial acetic acid solution, 18 to 21°C) and leave it in for approx. 30 seconds. This is to suspend development so as to prevent the film from becoming blotchy and to prolong the effectiveness of the fixer.
6. Immerse the film in a rapid acid hardening fixer (18 to 21°C) and leave it in for approximately ten minutes (the fixing time should be at least two or three times the time it takes for the negative to clear).
   This is to dissolve the photosensitive silver halide (white part of the film) and thereby make the unexposed part of the film transparent.

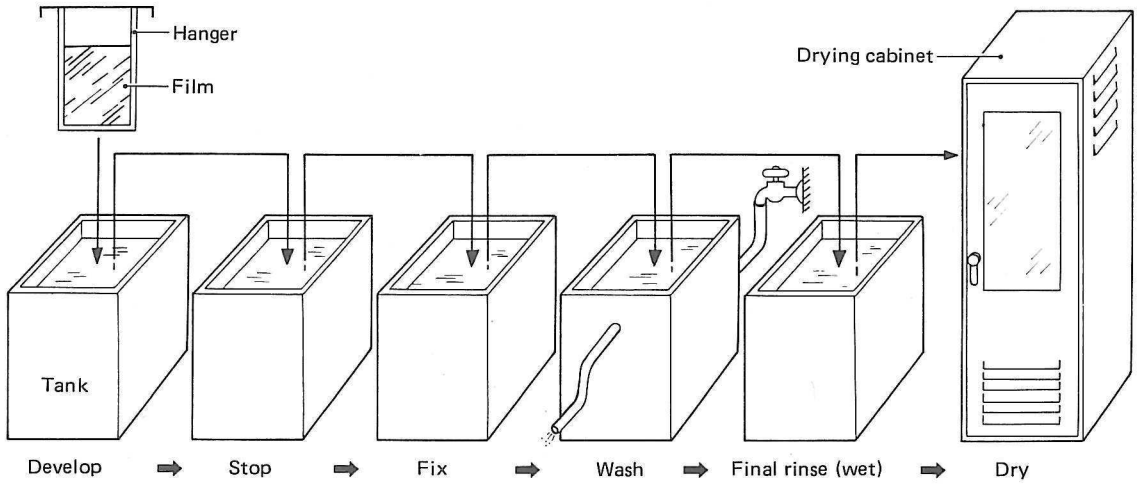


Fig. 5.2-32 Film processing

Thereafter, processing can be carried out under an ordinary light.

7. Wash the film in running water (15 to 20°C) for 30 to 60 minutes.

   This removes the complex salt and fixing solution. The washing time can be considerably reduced by immersing the film in a rinse accelerator prior to washing it in running water.

8. Immerse the film in a final rinse bath (weak solution of anionic surfactant, 18 to 21°C) and leave it in for approx. 30 seconds (or wipe both surfaces of the film carefully with a soft sponge).

   By so doing, film drying time is reduced and film blisters are prevented.

9. Dry the film in a drying cabinet (the cabinet need not be large), or dry it naturally by hanging it in a well-ventilated, dust-free place away from direct sunlight.

   Store the dried film in a negative bag (polyethylene, cellophane, etc.) and keep the bag in a dry place away from direct sunlight.

   Note: Consequences of faulty film processing, etc. are listed in Table 5.2 (assuming that the exposure is in order).

Table 5.2 Consequence of faulty film processing

Appearance	Possible cause
● No picture	○ Film inserted into cassette upside-down.
● Complete blackening	○ Magazine lid inadvertently opened while being carried.
● Fogging	○ Faulty safelight.
	○ Film processing date has expired.
● High density	○ Developer temperature too high.
● Low density	○ Developer temperature too low.
● Too grainy	○ Developing time too long.
● Uneven density	○ Developing time too short.
	○ Effete developer.
● Spotty staining (mottled)	○ Developer agitation insufficient.
	○ Film electrostatically charged before developing.
● Scratches, streaks	○ Film emulsion surface abrased.
● Discoloration of film during storage	○ Fixing and rinsing insufficient.
● Moldy film	○ Method and place of storage unsuitable.
	○ Drying insufficient.
● Extraneous particulates	○ Impurities in tap water.
● Blisters on film	○ Water droplets left on film before drying.
● Reticulation	○ Tap water temperature too high.

5.2.11 Keyboard operation

5.2.11a Page change

The page displayed on the CRT can be changed in two ways, as follows:

- By using the command keys (KB-1)

  PAGE-1 to PAGE-8 (Subsect. 4.2.8) are displayed one after another by depressing the PAGE key.

- By using the standard keys (KB-2)

1. When PAGE-1 or PAGE-2 is displayed on the CRT, make sure that no character is displayed on the bottom margin of the PAGE. If any character is displayed, change the PAGE by using the PAGE key (KB-1). When PAGE-7 is displayed, make sure that there is no cursor (■ mark) on the PAGE. If a cursor is on the PAGE, change the PAGE by using the PAGE key (KB-1).
2. Depress | P | G | the desired page number (1 to 8) | RETURN | .
   If "ERROR" appears in the bottom margin, carry out this step once again.

The contents of each page (8 pages in all) are found in Subsect. 4.2.8. CRT brightness can be adjusted with the CRT INTENSITY knob (R1-13).

5.2.11b O-VOLT setting

The O-VOLT setting is required for heating the gun filament without generating an accelerating voltage. This setting facilitates filament flashing when an LaB_6 filament is employed.

1. Set the FILAMENT knob (L1-2) to OFF.
2. Depress | O (zero) | V | O (oh) | L | T | RETURN | .
3. Switch on the HT button (L1-6).

The O-VOLT setting is automatically removed by generating an accelerating voltage with the ACCEL VOLTAGE switch (L1-5).

5.2.11c Recording by printer

By depressing the PRINT key (KB-1), the whole information displayed on the CRT is recorded by the printer (attachment).

5.2.11d PC board check

Whether each PC board is normal is displayed on the CRT when | C | H | E | C | K | RETURN | (KB-2) is depressed.

5.2.11e Changing the name of pole piece (displayed magnification and camera length)

When the objective lens and/or condenser lens pole piece(s) is(are) changed, the following procedure should be carried out so that incorrect magnification and camera length are not displayed on PAGE-1, and lens current, etc. do not become inadequate.

1. Obtain PAGE-1 on the CRT.
2. While keeping the CTRL key (KB-2) depressed, obtain an asterisk on the left upper corner of PAGE-1 (Fig. 5.2-33) with the A key (KB-2).

3. Depress | P | P | = | OL pole piece name | , | CL pole piece name | RETURN |. If "ERROR" appears in the bottom margin, carry out this step once again.

   Notes: 1. *An OL pole piece name is selected from among AHP, BLP, SAP, SHP, STP, UHP, etc. Generally AHP is selected. A CL pole piece name is either S (single-gap) or D (double-gap). D is generally used.*

   2. *Although the OL pole piece name is displayed on PAGE-1 (Fig. 5.2-33), the CL pole piece name is not displayed.*

4. While keeping the CTRL key (KB-2) depressed, erase the asterisk with the A key (KB-2).

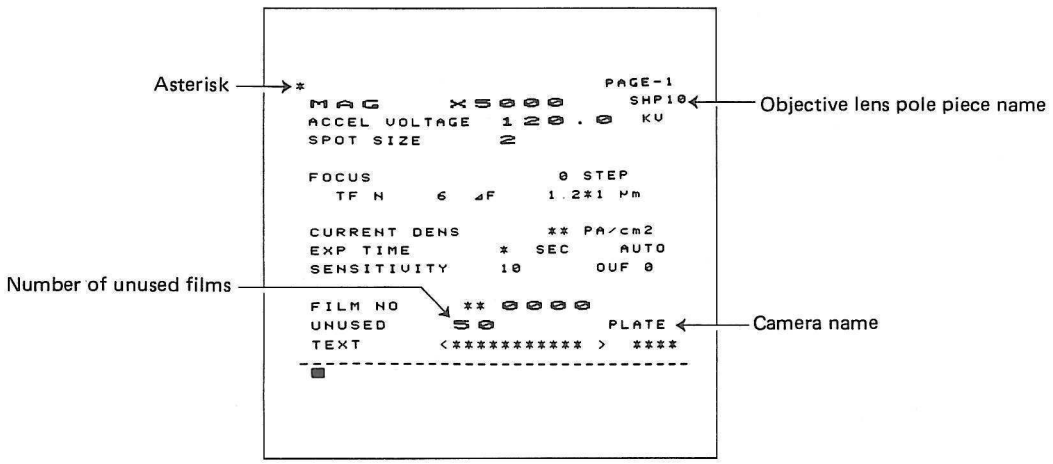


Fig. 5.2-33 PAGE-1

5.2.11f Character writing

- Characters can be written on PAGE-1, 2 and 7, and stored in the memory. When the key of the desired character is depressed, the character is written at the position marked with ■ (cursor) in the bottom margin of PAGE-1 and 2, or on PAGE-7, and at the same time, the ■ mark shifts to the next position.
- To shift the ■ mark left without writing any character, depress the ← key (KB-2) and if the ■ mark is to be shifted right without writing any character, depress the → key (KB-2).
- To erase a character, move the ■ mark to the position of the character to be erased with the ← or → key (KB-2) and then depress the space key (KB-2). If all the characters on PAGE-7 are to be erased, depress the TEXT key (KB-1) three or more times.
- To store the written characters in the memory, depress the RETURN key (KB-2) in the case of PAGE-1 and 2. In the case of PAGE-7, depress the PAGE key (KB-1).
- If (an) inadequate character(s) have(has) been written, "ERROR" appears in the bottom margin of PAGE-1 or 2 when the RETURN key (KB-2) is depressed. In such case, erase "ERROR" by re-displaying the same PAGE with the PAGE key (KB-2), then write (an) adequate character(s).

5.2.11g Writing the TEXT

Any characters not exceeding 17 characters (12 in patentheses and 5 outside them) can be written on the TEXT line of PAGE-1. The characters written inside parentheses are printed on the film when photographing.

1. Depress the TEXT key (KB-1). "TEXT" now appears in the bottom margin of PAGE-1 (Fig. 5.2-34).
2. Write the desired characters in the margin (Subsect. 5.2.11f).
3. Depress the RETURN key (KB-2).

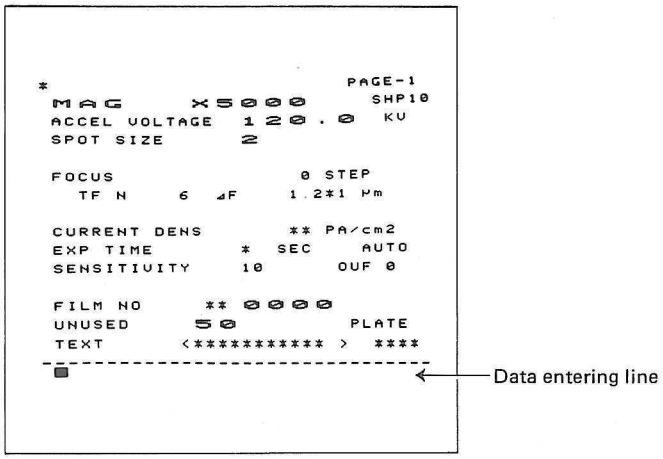


Fig. 5.2-34 TEXT writing

5.2.11h Setting the minimum amount of accelerating voltage change

- When the amount of voltage per step is 0.1 ~ 20.0 kV:

1. Obtain PAGE-1 with the PAGE key (KB-1).
2. Depress [H][T]. "HT STEP = kV/STEP" appears in the bottom margin of PAGE-1.
3. Depress [0][0][1][0], [0][0][2][0] . . . . . or [2][0][0][0].
4. Depress the RETURN key (KB-2). If "ERROR" appears in the bottom margin, start again from Step 2.

- When the amount of voltage per step is 0.05 kV:

1. While keeping the CTRL key (KB-2) depressed, obtain an asterisk on the left upper corner of PAGE-1 (Fig. 5.2-33) with the A key (KB-2).
2. Depress [S][T][E][P][=][O][N][RETURN].
3. While keeping the CTRL key (KB-2) depressed, erase the asterisk with the A key (KB-2).
4. Obtain PAGE-1 with the PAGE key (KB-1), then depress [H][T][0][0][0][5][RETURN].

5.2.11i Storing in the memory the position of the field of view

The position of the field of view appearing on the fluorescent screen, specimen position in other words, is displayed on PAGE-2 by a coordinate and graph.

1. Obtain PAGE-2 with the PAGE key (KB-1).
2. Depress [S][P]. "SPECIMEN POSITION =" appears in the bottom margin of PAGE-2.
3. Depress the 0, 1 or 2 key (KB-2) corresponding to the line number where the current specimen position is to be stored (see Subsect. 5.2.11f).
4. Depress the RETURN key (KB-2). If "ERROR" appears in the bottom margin, start again from Step 2.

When all the specimen positions displayed on PAGE-2 are to be erased, depress [0 (zero)][P][0 (oh)][S][I] [RETURN].

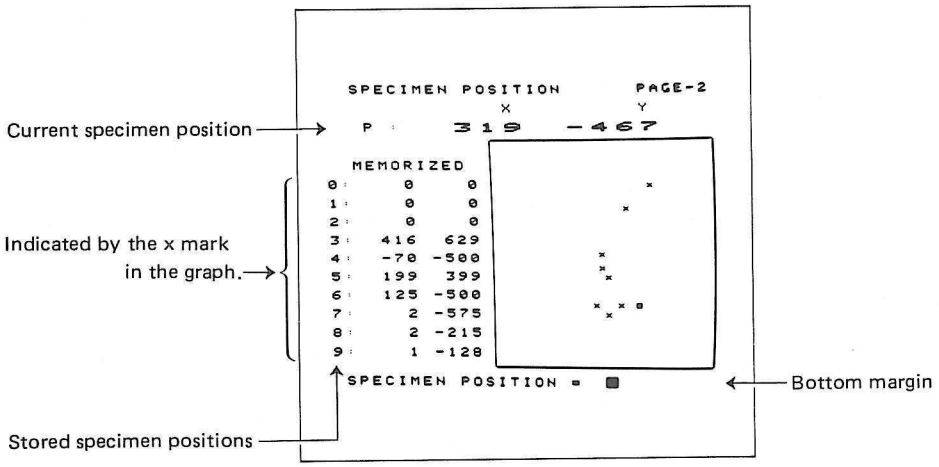


Fig. 5.2-35 PAGE-2

5.2.11j Setting the film number and number of unused films

Of the six characters displayed on the FILM NO line of PAGE-1, the last four are the film number which advances by one every time a film is exposed, but the first two remain unchanged unless rewritten by the operator. The number displayed on the UNUSED line is the number of unused films (Fig. 5.2-33) which is reduced by one every time a film is exposed. The six characters displayed on the FILM NO line are printed on the film at the time of exposure.

1. Depress the F NO key (KB-1). "FILM NO" and "UNUSED" appear in the bottom margin of PAGE-1.
2. Write the desired characters in the bottom margin (see Subsect. 5.2.11f).
3. Depress the RETURN key (KB-2). If "ERROR" appears in the bottom margin, start again from Step 1.

5.2.11k Selecting the camera

When the standard camera is to be used, first obtain PAGE-1 with PAGE key (KB-1), then depress [F][I][L][M][=][P][L][A][T][E][RETURN]. When a 35 mm camera is to be used, depress [A][3][5] instead of PLATE. "PLATE" or "A35" appears at the end of UNUSED line.

5.2.11ℓ Setting the exposure index

The exposure time of automatic exposure can be changed by changing the SENSITIVITY number on PAGE-1 through the keyboard.

1. Obtain PAGE-1 with the PAGE key (KB-1).
2. Depress [S][E]. "FILM SENSITIVITY" appears in the bottom margin of PAGE-1.
3. Write the desired number (1 to 20) in the bottom margin through the keyboard. The larger the number, the shorter the exposure time for the same image brightness.
4. Depress the RETURN key (KB-2).

5.2.11m Storing the lens system condition and setting the lens system to the stored condition

Ten types of lens system can be stored in the memory, or the lens system can be set to any of the stored conditions.

- To store the operating conditions:

1. Obtain PAGE-1 with the PAGE key (KB-1).
2. Depress [U][F][space key][I][N][RETURN]. "U.F. MEMORY IN" appears in the bottom margin of PAGE-1.
3. Select the desired position (number) out of ten (0, 1, . . . 9) storing positions and write it in the bottom margin through the keyboard (see Subsect. 5.2.11f).
4. Depress the RETURN key (KB-2).

- To set the stored operating conditions:

1. Obtain PAGE-1 with the PAGE key (KB-1).
2. Depress [U][F][space key][O][U][T][RETURN]. "U.F. MEMORY OUT" appears in the bottom margin of PAGE-1.
3. Write the number of memory position, where the desired lens system is stored, in the bottom margin through the keyboard.
4. Depress [D, L or space key][RETURN].

   If all the beam deflector currents (except those for the electron gun beam deflectors, spot alignment coil, intermediate stigmator and projector lens beam deflector) are to be reproduced, the D key (KB-2) should be depressed before the RETURN key is depressed. If all the lens currents are to be reproduced, the L key (KB-2) should be depressed. If the space key is depressed, both the beam deflector currents and lens currents are reproduced.

5.2.11n Setting the through-focus series condition

The number of films to be exposed and the amount of focus change per film can be set (see Subsect. 5.6.3).

5.2.11o Setting the amount of OUF (optimum underfocus)

1. Obtain PAGE-1 with the PAGE key (KB-1).
2. Depress | O (oh) | U | . "OUF NO =" appears in the bottom margin of PAGE-1.
3. Write 1, 2 or 3 in the margin through the keyboard. If the OUF is not required, write 0 (zero) instead of 1, 2, or 3.

   Note: The amounts of underfocus when 1, 2 or 3 is written are 1-, 2- or 4-times the preset value, when the IMAGE X (or Y) button (R1-4) is depressed. When the IMAGE X and Y buttons are depressed, the amount of underfocus is twice that set up when either IMAGE X (or Y) button is depressed.
4. Depress the RETURN key (KB-2). If "ERROR" appears in the margin, restart from Step 2. When the RETURN key is depressed, the OUF number is displayed on the end of the SENSITIVITY line of PAGE-1.

5.2.11p Setting the mode of minimum exposure operation

Refer to Subsect. 5.6.4.

5.2.11q Setting the basic magnification

1. Depress the MAG2 button (R1-8).
2. Obtain PAGE-1 with the PAGE key (KB-1).
3. Select the desired magnification with the SELECTOR switch (R1-9).
4. Depress | M | A | G | 2 | RETURN | .

5.2.11r Writing USER'S COMMENTS

Obtain PAGE-7 with the PAGE key (KB-1) and write comments referring to Subsect. 5.2.11f.

Notes: 1. Use the RETURN key (KB-2) to start a new paragraph. To move the ■ mark downwards, use the LINE FEED key (KB-2).

2. If the ■ mark does not appear, re-obtain PAGE-7 with the PAGE key (KB-2) to display the mark. No character can be written on PAGE-7 unless the mark has appeared.

5.2.12 Shutdown procedure

5.2.12a Complete shutdown

1. Turn the FILAMENT knob (L1-2) to OFF and depress the HT button (L1-6) to turn off the accelerating voltage.
2. Remove the specimen holder (pull, turn counterclockwise, and draw out), cover the holder with the protector. and store the holder in the specimen holder box (Fig. 5.2-7).
3. Set the POWER switch (L1-3) to OFF, and wait 5 to 10 minutes.
4. After the microcope has completely shut down, close the cooling water faucet and turn off the main power switch on the distribution board.

5.2.12b Shutdown without switching off the SIP

The microscope can be shutdown without switching off the SIP (ion pump, optional), if desired, in order to evacuate the microscope column with the SIP round the clock, as follows:

1. Make sure, if the SIP is incorporated, that the EM-ACD (anticontamination device, optional) temperature is at room temperature. If not, refer to Subsect. 6.5.2.
2. Turn off the accelerating voltage and remove the specimen as per steps 1 and 2 in Subsect. 5.2.11a.
3. Turn on the UNATTENDED OPERATION switch on the POWER SUPPLY front panel.
4. Set the POWER switch (L1-3) to OFF and wait for 5 to 10 minutes.
5. After the evacuation system has shut down, close the cooling water faucet.

5.2.13 Data printout on micrograph (Fig. 5.2-36)

a. Specimen name, etc.: Entered from the keyboard (see Subsect. 5.2.11g).

b. Micron bar: The calibrated length of the bar corresponds to the length on the specimen.

c. Film number: Six digits (the last four digits indicate the film number and the first two are optionally entered for other identification).

d. Accelerating voltage

e. Magnification c

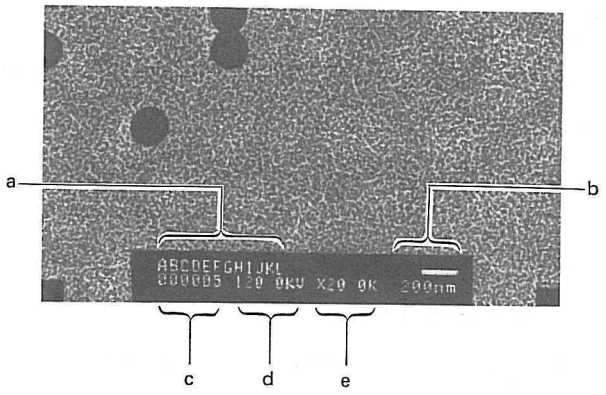


Fig. 5.2-36 Data printout on micrograph

5.3 Method B

This section covers the column alignment procedure required when the microscope conditions are unknown after overhauling or pole piece replacement. Procedures detailed in method A are skeletonized in this section. Practice method A (Sect. 5.2) repeatedly before attempting method B. See method C (Sect. 5.4) for routine operation.

1. Generate an electron beam.
   - 1a. Generate an accelerating voltage, remove all the apertures and specimen from the electron beam path, and set the FILAMENT knob to the stopper position.
   - 1b. Set the magnification to 5,000 times.
   - 1c. Set the GUN ALIGN knobs (GA-1, 2) to the midway positions. These are multi-turn knobs.
   - 1d. Obtain the brightest electron beam with the GUN ALIGN: SHIFT knobs (GA-1).
2. Carry out electron gun alignment.
   - 2a. Set the spot size (indicated on PAGE-1) to 1L with the SPOT SIZE switch (L1-8). If the S button (L1-19) is bright, PAGE-1 does not display 1L but S. In this case depress the S button to make it dim.
   - 2b. Gradually converge the electron beam with the BRIGHTNESS knob (L1-14). If the beam moves off the screen center, center it with the GUN ALIGN: SHIFT knobs (GA-1). When the beam brightness decreases, increase the brightness with the GUN ALIGN: TILT knobs (GA-2).
   - 2c. Obtain the smallest electron beam with the BRIGHTNESS knob, center it with the GUN ALIGN: SHIFT knobs, and adjust the GUN ALIGN: TILT knobs to obtain the brightest beam.
3. Carry out condenser lens alignment.
   - 3a. Set the spot size to 3L.
   - 3b. Gradually converge the electron beam with the BRIGHTNESS knob (L1-14). If the beam moves off the screen center, center it with the left and right SHIFT knobs (L1-16, R1-1).
   - 3c. Carry out Step 2.
   - 3d. Repeat Steps 2 and 3 until the electron beam deviation from the screen center ceases.
4. Carry out CM lens (condenser mini-lens) alignment.
   - 4a. Make sure that the S button (L1-19) is switched off (dim) and set the magnification to 10,000 times.
   - 4b. Turn off the CM button (L1-18).
   - 4c. Set the left and right DEF knobs (L1-17, R1-2) to the midway positions.
   - 4d. While keeping the electron beam to the screen center with the left and right SHIFT knobs (L1-16, R1-1), converge the electron beam with the BRIGHTNESS knob (L1-14).
   - 4e. Turn on the CM button (L1-18).
   - 4f. While keeping the beam to the screen center with the condenser mini-lens shifting screws (Fig. 5.3-1),

converge the beam with the BRIGHTNESS knob (L1-14).

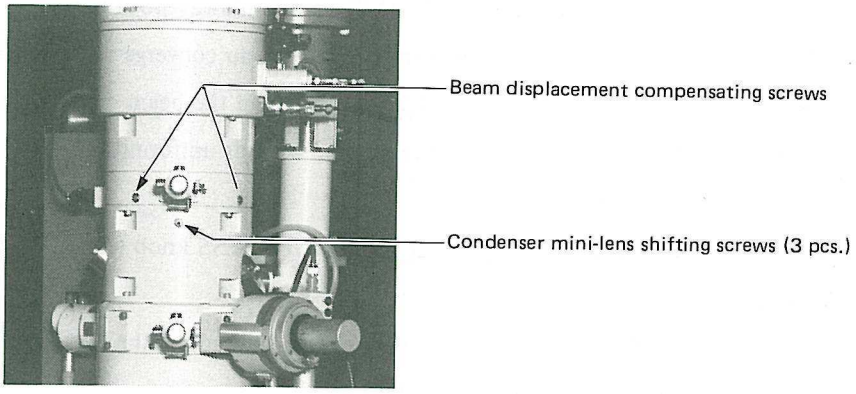


Fig. 5.3-1

5. Insert the condenser lens aperture and correct the condenser lens astigmatism.
   5a. Insert the condenser lens aperture into the beam path (Subsect. 5.2.5).
   5b. Obtain the smallest electron beam with the BRIGHTNESS knob (L1-14) and turn the knob back and forth from the position where the smallest beam is obtained. If the beam converges and spreads concentrically, proceed to Step 6. If the beam is elliptical just before and after the beam is maximally converged, turn on the COND STIG button (L1-15), make the beam round with the left and right DEF knobs (L1-17, R1-2), and turn off the COND STIG button.
6. Carry out objective lens current rough adjustment.
   6a. Turn on the S button (L1-19) and turn the α-SELECTOR knob (L1-20) fully clockwise.
   6b. Obtain an electron beam with the size of $2 \sim 3$ cm in diameter with the BRIGHTNESS knob (L1-14).
   6c. Turn on the IMAGE X or Y button (R1-4). The beam is now separated into two.
   6d. Make the separated beams a single beam with OBJ FOCUS knob (R1-3).
   6e. Turn off the IMAGE X and Y buttons (R1-4) and S button (L1-19).
7. Carry out the electron gun and condenser lens alignment.
   7a. Perform Step 2.
   7b. Perform Step 3.
   7c. Perform Step 6.
8. Compensate the beam displacement caused by the objective lens.
   8a. Insert a specimen into the beam path, and set the specimen tilt angle to zero (see Subsect. 5.2.6).

8b. Turn on the BRIGHT TILT and S buttons (L1-15, 19), and turn the α-SELECTOR knob (L1-20) fully clockwise.

8c. Obtain the smallest electron beam with the BRIGHTNESS knob (L1-14).

8d. Set the left and right DEF knobs (L1-17, R1-2) to the midway positions.

8e. Turn on the OBJ button (R1-4). The beam commences to converge and spread.

8f. Adjust the left and right SHIFT knobs (L1-16, R1-1) and the beam displacement compensating screws (Fig. 5.3-1) so that the beam converges and spreads uniformly.

9. Align the condenser mini-lens precisely.

9a. Turn off the S button (L1-19) and adjust the BRIGHTNESS knob (L1-14) so that the beam covers the entire screen.

9b. Make sure that the OBJ button (R1-4) is turned on and adjust the condenser mini-lens shifting screws (Fig. 5.3-1) so as to minimize the image shift.

9c. Turn off the OBJ button (R1-4).

10. Adjust the image wobbler deflection angle.

10a. Obtain the smallest beam with the BRIGHTNESS knob (L1-14) and turn on the IMAGE X button (R1-4).

10b. Make the separated beams a single beam with the IMAGE WOBBLER ADJ: X knobs (R2-2).

10c. Turn off the IMAGE X button and turn on the IMAGE Y button (R1-4).

10d. Make the separated beams a single beam with the IMAGE WOBBLER ADJ: Y knobs (R2-2).

10e. Turn off the IMAGE Y button (R1-4).

11. Carry out current center alignment.

11a. Set the magnification to 25.000 times and expand the beam with the BRIGHTNESS knob (L1-14) cover the entire screen.

11b. Turn on the OBJ button (R1-4).

Note: The image now rotates clockwise and counterclockwise periodically. The center of the image rotation in this case is referred to as the current center.

11c. After making sure that the BRIGHT TILT button (L1-15) is turned on, bring the current center to the screen center with the left and right DEF knobs (L1-17, R1-2).

11d. Turn off the OBJ button (R1-4).

12. Carry out the intermediate lens alignment and astigmatism correction.

12a. Turn on the DIFF button (R1-8) and spread the beam with the BRIGHTNESS knob (L1-14).

12b. Set the projector lens beam deflector coil current (indicated on PAGE-5) to zero with the PROJ ALIGN knobs (R2-3).

12c. Set the camera length (indicated on PAGE-1) to ~~220~~ about 200 cm with the SELECTOR switch (R1-9).

12d. Obtain a caustic spot with the DIFF FOCUS knob (R1-10).

12e. Center the spot with the intermediate lens shifting screws (Fig. 5.3-2).

12f. Set the camera length to about 20 cm with the SELECTOR switch (R1-9) and obtain a caustic spot with the DIFF FOCUS knob (R1-10).

12g. Center the spot with the projector lens shifting screws (Fig. 5.3-2).

12h. Repeat Steps 12c through 12g until the caustic spot ceases to move off the screen center.

12i. Obtain a caustic image with the DIFF FOCUS knob (R1-10) and make the image round with the INT STIG knobs (R2-4).

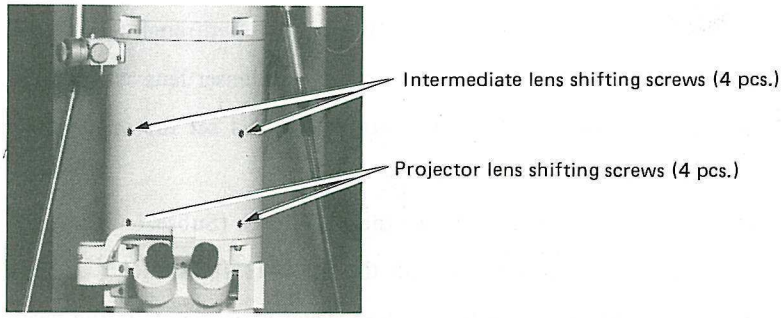


Fig. 5.3-2

13. Carry out voltage center alignment.

13a. Set the magnification to 100,000 times.

13b. Adjust the BRIGHTNESS knob (L1-14) so that the electron beam covers the entire screen.

13c. Turn on the HT button (R1-4).

Note: The image now enlarges and contracts periodically. The center of the image movement in this case is referred to as the voltage center.

13d. After confirming that the BRIGHT TILT button (L1-15) has been turned on, bring the voltage center to the screen center with the left and right DEF knobs (L1-17, R1-2).

13e. Turn off the HT button (R1-4).

14. Insert the objective lens aperture into the beam path (Subsect. 5.2.7).

15. Carry out S mode (micro-area illumination mode) alignment.

15a. Turn on the S button (L1-19) and turn the α-SELECTOR knob (L1-20) fully clockwise.

15b. Set the magnification to 50,000 times.

15c. Turn on the HT button (R1-4).

15d. After confirming that the BRIGHT TILT button (L1-15) has been turned on, adjust the left and right DEF knobs (L1-19, R1-2) so that the electron beam expands and contracts uniformly.

15e. Turn off the S and HT buttons (L1-19, R1-4).

5.4 Method C

This section covers the routine operation of the microscope. Practice method A (Sect. 5.2) repeatedly before attempting method C. If a high resolution image is to be obtained, see also Section 5.5. If the illumination spot disappears from the fluorescent screen in the course of the operation in method C, carry out the operation in method B (Sect. 5.3).

5.4.1 Alignment

1. Generate an accelerating voltage, remove all the apertures and specimen from the beam path and set the FILAMENT knob (L1-2) to the stopper position (Steps 1 through 9, Subsect. 5.2.4).
2. Insert the condenser lens aperture and correct the condenser lens astigmatism.
   - 2a. Confirm that the S button (L1-19) is turned off and set the spot size (indicated on PAGE-1) to 3L with the SPOT SIZE switch (L1-8).
   - 2b. Insert the condenser lens aperture into the beam path (Subsect. 5.2.5).
   - 2c. Obtain the smallest electron beam with the BRIGHTNESS knob (L1-14) and turn the knob back and forth from the position where the smallest beam is obtained. If the beam converges and spreads concentrically, proceed to Step 6. If the beam is elliptical just before and after the beam is maximally converged, turn on the COND STIG button (L1-15), make the beam round with the left and right DEF knobs (L1-17, R1-2), and turn off the COND STIG button.
3. Carry out the objective lens current rough adjustment.
   - 3a. Turn on the S button (L1-19) and turn the α-SELECTOR knob (L1-20) fully clockwise.
   - 3b. Obtain an electron beam 2 ~ 3 cm in diameter with the BRIGHTNESS knob (L1-14).
   - 3c. Turn on the IMAGE X or Y button (R1-4). The beam is now separated into two.
   - 3d. Make the separated beams a single beam with OBJ FOCUS knob (R1-3).
   - 3e. Turn off the IMAGE X and Y buttons (R1-4) and S button (L1-19).
4. Insert a specimen into the beam path and set the specimen X-tilt angle to zero (Subsect. 5.2.6).
5. Carry out current center alignment.
   - 5a. Set the magnification to 25,000 times and expand the beam with the BRIGHTNESS knob (L1-14) to cover the entire screen.
   - 5b. Turn on the OBJ button (R1-4).

     Note: The image now rotates clockwise and counterclockwise periodically. The center of the image rotation in this case is referred to as the current center.
   - 5c. After making sure that the BRIGHT TILT button (L1-15) is turned on, bring the current center to the screen center with the left and right DEF knobs (L1-17, R1-2).

5d. Turn off the OBJ button (R1-4).

6. Carry out voltage center alignment.

6a. Set the magnification to 100,000 times.

6b. Adjust the BRIGHTNESS knob (L1-14) so that the electron beam covers the entire screen.

6c. Turn on the HT button (R1-4).

Note: The image now enlarges and contracts periodically. The center of the image movement in this case is referred to as the voltage center.

6d. After confirming that the BRIGHT TILT button (L1-15) has been turned on, bring the voltage center to the screen center with the left and right DEF knobs (L1-17, R1-2).

6e. Turn off the HT button (R1-4).

7. Insert the objective lens aperture into the beam path (Subsect. 5.2.7).

8. Carry out S mode (micro-area illumination mode) alignment.

8a. Turn on the S button (L1-19) and turn the α-SELECTOR knob (L1-20) fully clockwise.

8b. Set the magnification to 50,000 times.

8c. Turn on the HT button (R1-4).

8d. After confirming that the BRIGHT TILT button (L1-15) has been turned on, adjust the left and right DEF knobs (L1-19, R1-2) so that the electron beam expands and contracts uniformly.

8e. Turn off the S and HT buttons (L1-19, R1-4).

9. Check the filament image.

When a tungsten filament is in use, check the filament image as follows. If an LaB_6 (LKS) filament is in use, however, check the filament image referring to the LKS Instruction manual.

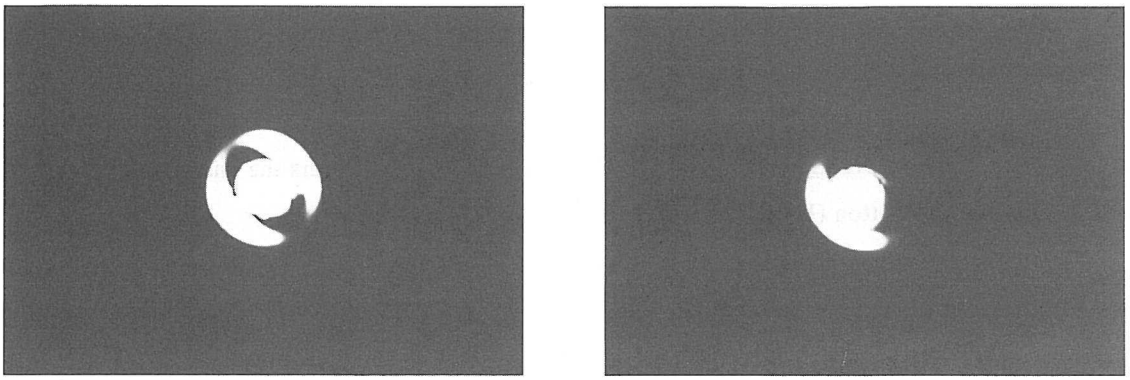
9a. Maximally converge the electron beam with the BRIGHTNESS knob (L1-14).

9b. While observing the illumination spot on the fluorescent screen, gradually turn the FILAMENT knob (L1-2) counterclockwise so as to obtain a filament image (Fig. 5.4-1).

9c. If the filament image is asymmetrical (this indicates that the electron gun is misaligned), make it symmetrical, as shown in Fig. 5.4-1a, with the GUN ALIGN: TILT knobs (GA-2).

9d. Turn the FILAMENT knob (L1-2) clockwise until the filament image disappears (saturation position), and then set the stopper to this position of the knob.

Note: If the FILAMENT knob (L1-2) is set beyond the saturation position, the life of the filament will be considerably shortened. The saturation position changes a little as time passes. It may also change when the accelerating voltage or beam current is changed. Therefore, be sure to check the saturation position when the accelerating voltage or beam current is changed.



a: When electron gun is aligned

b: When electron gun is misaligned

Fig. 5.4-1 Filament image

5.4.2 Objective lens astigmatism correction

If astigmatism exists in the objective lens, the focal length differs depending on the beam direction and focusing becomes unidirectional. Therefore, astigmatism must be corrected in order to focus the image in every direction. For astigmatism correction, it is necessary to distinguish between the in-focus and slightly-out-of-focus state of the image. See also the method for focusing with the aid of the Fresnel fringe (Sect. 5.4.3) when correcting objective lens astigmatism.

1. Carry out routine column alignment (Sect. 5.4.1).

   Note: Perforated, thin plastic film reinforced with carbon is recommended as an ideal test specimen for objective lens astigmatism correction. At high magnifications, background structure in the film image (phase contrast) is used for correcting astigmatism (see Sect. 5.5); in which case, specimen supporting film or even a thin specimen without supporting film may well serve the purpose.

2. Obtain a magnification of 5000×, and focus the image using the image wobbler.
   - 2a. Depress the MAG 2 button (R1-8), and manipulate the BRIGHTNESS knob (L1-14) to spread the illumination spot so that it covers the whole fluorescent screen.
   - 2b. Depress the IMAGE X or Y button (R1-4).
   - 2c. Manipulate the OBJ FOCUS knobs (R1-3) to obtain a single stationary image.
   - 2d. Release the IMAGE X or Y button (R1-4).
3. Obtain a magnification 1−1.5 times the photographing magnification. Adjust the image brightness with the BRIGHTNESS knob (L1-14), and center the illumination with the SHIFT: X and Y knobs (L1-16, R1-1).
4. Insert the small fluorescent screen into the electron beam path, and focus the binoculars on the small fluorescent screen.
5. Select the field of view with the left and right specimen shifting knobs, and bring a hole image of about 5mm in dia. to the small fluorescent screen.

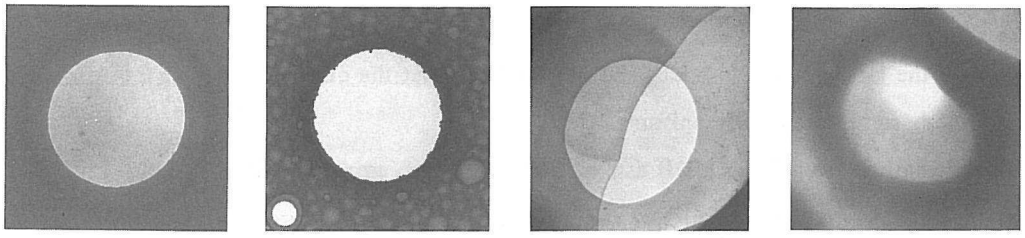
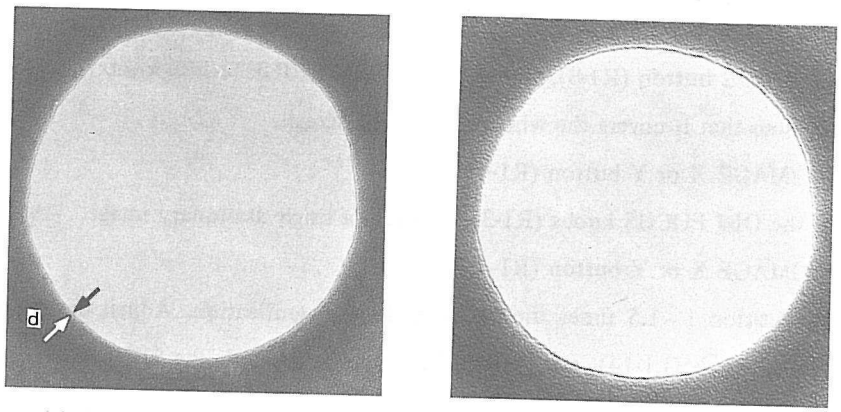


Fig. 5.4-2 Test hole for astigmatism correction

Note: The test hole used for astigmatism correction should be round and have a smooth circumference as shown in Fig. 5.4-2a. A hole having an uneven circumference, covered by another film, or heavily contaminated by electron beam irradiation, or heavily contaminated by electron beam irradiation, as shown in Fig. 5.4-2b, c, d, is unsuitable.

6. Depress the OBJ STIG 1 button (L1-15).
7. Slightly overfocus the hole image with the OBJ FOCUS knobs (R1-3) to check astigmatism.
   When the hole image is overfocused, a dark fringe (Fresnel fringe) appears around the edge of the hole; when underfocused, a bright fringe appears around the edge of the hole.
   If the distance (d) between the fringe and the edge of the hole is even all around as shown in Fig. 5.4-3a, there is no astigmatism and the following steps can be omitted. If the distance is uneven as shown in Fig. 5.4-3b, correct the astigmatism as described below.



a: Fresnel fringe when astigmatism does not exist **b: Fresnel fringe when astigmatism exists**

Fig. 5.4-3 Objective lens astigmatism

Note: If the distance between the fringe and the edge of the hole is too large, it will be difficult to check astigmatism. The distance should be so small that the gap between the fringe and the edge of the hole is just discernible.

8. Manipulate the DEF: X and Y knobs (L1-17, R1-2) so that the distance between the fringe and the edge of the hole becomes practically uniform.
9. Check astigmatism (Step 7) again. If astigmatism still exists, correct it (Step 8).

   Note: If the objective lens aperture or the specimen is dirty, or the objective lens aperture is not correctly inserted in the beam path, or the current center is not properly set, it may be impossible to correct astigmatism completely.

10. Release the OBJ STIG 1 button (L1-15).

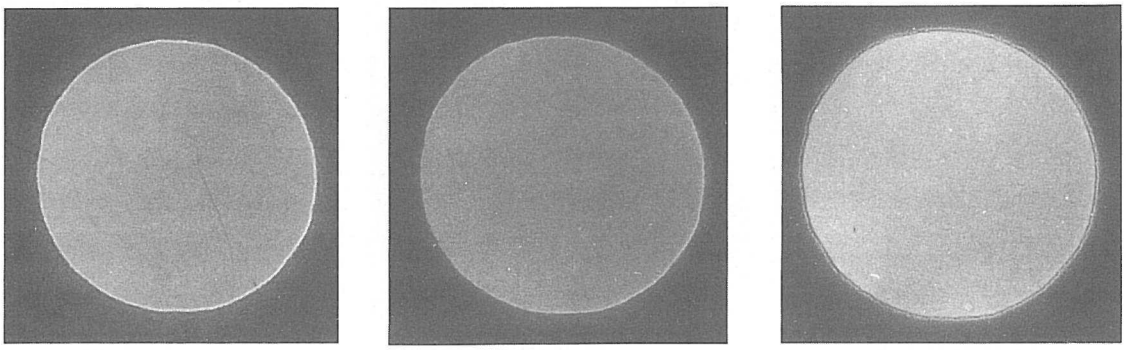
    Note: When the OBJ STIG 1 button switch (L1-15) is off, manipulation of the DEF: X and Y knobs (L1-17, R1-2) does not affect astigmatism.

5.4.3 Focusing

This subsection describes how to focus the image using the Fresnel fringe. (The focusing method using the image wobbler is described in Sect. 5.2.) At lower magnifications, focusing using the image wobbler is easier, but at higher magnifications, it is easier to focus with the aid of the Fresnel fringe. See the focusing method utilizing the background structure (Sect. 5.5) for focusing the image at very high magnifications. See also the through-focus method (Sect. 5.6) in which the focus is automatically changed in several steps every time a film is exposed.

1. Manipulate the OBJ FOCUS knobs (R1-3) to obtain the sharpest possible image (coarse focusing).
2. While observing a portion of the image having the greatest contrast (a film hole or dust particle is ideal for practice purpose) through the binoculars, turn the OBJ FOCUS: FINE knob (R1-3) slightly counterclockwise and clockwise, to set it where the image is in-focus.

   If a film hole is used, a bright, high contrast fringe (Fresnel fringe) forms around the edge of the hole, as shown in Fig. 5.4-4a, when the FINE knob is turned counterclockwise. This is referred to as the underfocus condition, a condition in which the contour width increases as the amount of underfocus is increased. When the FINE knob is turned clockwise, a dark fringe (Fresnel fringe) appears slightly apart from the edge of the hole as shown in Fig. 5.4-4c. This is referred to as the overfocus condition, a condition in which the distance between the fringe and the edge of the hole increases as the amount of overfocus is increased. In-focus lies between underfocus and overfocus. As the knob is gradually turned clockwise from the underfocus condition, the width of the bright fringe forming the hole contour decreases. When the fringe disappears and contour contrast is minimum as shown in Fig. 5.4-4b, the image is in-focus (the in-focus image may appear to be somewhat obscure, but it should not be construed that it is out of focus). As the knob is turned further clockwise, the image assumes an ambiguous state and appears as either an in-focus or overfocused image. (This is caused by the fact that the resolving power of the fluorescent screen is less than that of the film. If the image is photographed in this state, an overfocus fringe will be observed.) Immediately after the image has assumed such a state, a dark fringe appears slightly away from the edge of the hole (overfocus) as the knob is turned further clockwise. Fig. 5.4-5 shows this continuous change schematically.



a: Underfocus b: In-focus c: Overfocus

Fig. 5.4-4 Focusing with the aid of the Fresnel fringe

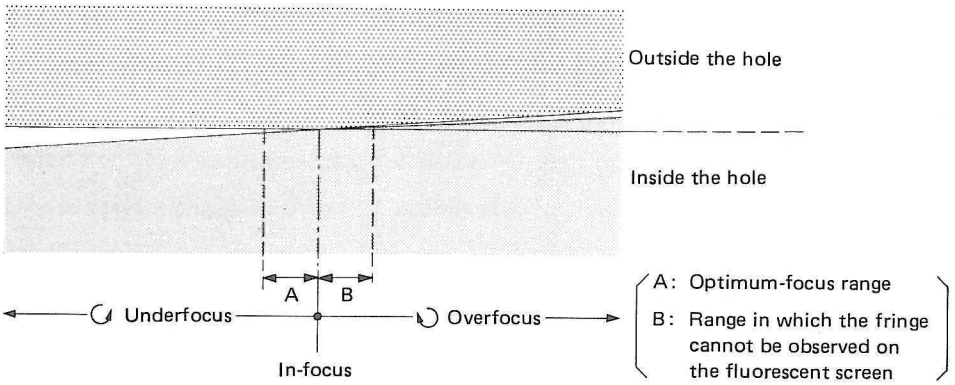
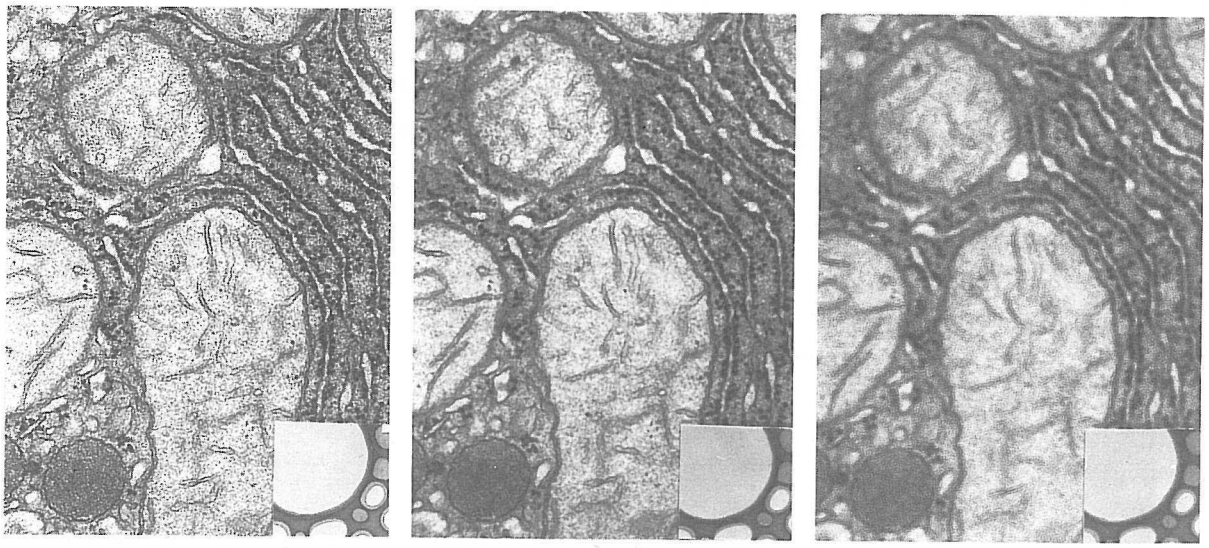


Fig. 5.4-5 Schematic diagram showing various focus conditions

3. Set the OBJ FOCUS: FINE knob (R1-3) to the in-focus position or slightly underfocus position (obtained by turning the knob slightly counterclockwise from the in-focus position).

   In the case of low-contrast specimens (such as very thin biological sections), the image should be slightly underfocused in order to obtain a sufficiently sharp image. In order to distinguish the focus suitable for photography from in-focus, it is called 'optimum' focus (Fig. 5.4-5-A).

   Fig. 5.4-6 shows a very thin biological section photographed under various focal conditions. In the figure, (a) is an optimum-focus (slightly underfocused) image, (b) is an in-focus image, and (c) is an overfocused image. If the OBJ FOCUS: FINE knob (R1-3) is turned counterclockwise beyond the optimum-focus range, the image becomes indistinct like a relief and the resolution deteriorates drastically. If the image is overfocused, it becomes impossible to interpret the image correctly. Never use an overfocused image for photography.



a: Optimum-focus **b: In-focus** **c: Overfocus**

Fig. 5.4-6 Practical example of focusing

Note: It is rather difficult to focus an image of very low contrast using the Fresnel fringe. Accordingly, in such case, if the magnification is relatively low, use the image wobbler, or set the OBJ FOCUS: FINE knob (R1-3) to the position where the contrast is lowest (almost the in-focus position) by turning it clockwise from the underfocus side. This method, however, requires some experience.

5.4.4 Image recording

Automatic exposure requiring films to be advanced one by one, described in Sect. 5.2, is omitted in this subsection. See Sect. 5.8 for photography of a tilted specimen.

5.4.4a Manual exposure

Use this method if the exposure time is to be freely set without using the exposure meter.

1. Release the SHUTTER AUTO button (R1-6) and FILM ADVANCE AUTO button (R1-7).
2. Select the desired magnification and field of view, and focus the image.
3. Set the exposure time.
   3a. Let the CRT display PAGE-1.
   3b. Set the EXP TIME value on PAGE-1 to the desired exposure time with the EXP TIME switch (R1-5).
4. Depress the PHOTO button (L1-12). When the built-in lamp lights up, depress the button again.

5.4.4b Continuous photography

In this method, an unexposed film is automatically advanced to the exposing position every time the image is photographed.

1. Depress the FILM ADVANCE AUTO button (R1-7).
2. Select the desired magnification and field of view, and focus the image.
3. Adjust the image brightness. In the case of manual exposure, set the exposure time.
4. After confirming that the PHOTO button (L1-12) lamp is lit, depress the PHOTO button (L1-12). The first film is now exposed. Repeat Steps 2 to 4 for the second and later films. For the last exposure, however, carry out Step 5.
5. For the last exposure, proceed as follows:
   5a. Release the FILM ADVANCE AUTO button (R1-7).
   5b. Select the desired magnification and field of view, focus the image, and adjust the image brightness or exposure time.
   5c. Depress the PHOTO button (L1-12).
   5d. When the built-in lamp of the PHOTO button (L1-12) lights up, depress the button again.

5.4.4c Multiple exposure

By using this method, a film can be exposed as many times as required.

1. Select the desired magnification and field of view, and focus the image.
2. Adjust the image brightness. In the case of manual exposure, set the exposure time.

3. If the built-in lamp of the PHOTO button (L1-12) is not lit, depress the PHOTO button (L1-12), and wait for the built-in lamp to light up.
4. After confirming that the built-in lamp of the PHOTO button (L1-12) is lit, depress the button. The large fluorescent screen now becomes upright, the film is exposed (the EXP lamp (L1-13) lights up and remains lit while the shutter is open), and the large fluorescent screen then returns to the horizontal position. When the large fluorescent screen starts returning to the horizontal position, redepress the PHOTO button (L1-12) before the screen becomes completely horizontal.
5. By repeating Steps 1 to 4, expose the film as many times as required. After the last exposure, however, do not depress the PHOTO button (L1-12) when the large fluorescent screen starts returning to the horizontal position.

5.4.5 Beam deflector current adjustment in the S mode

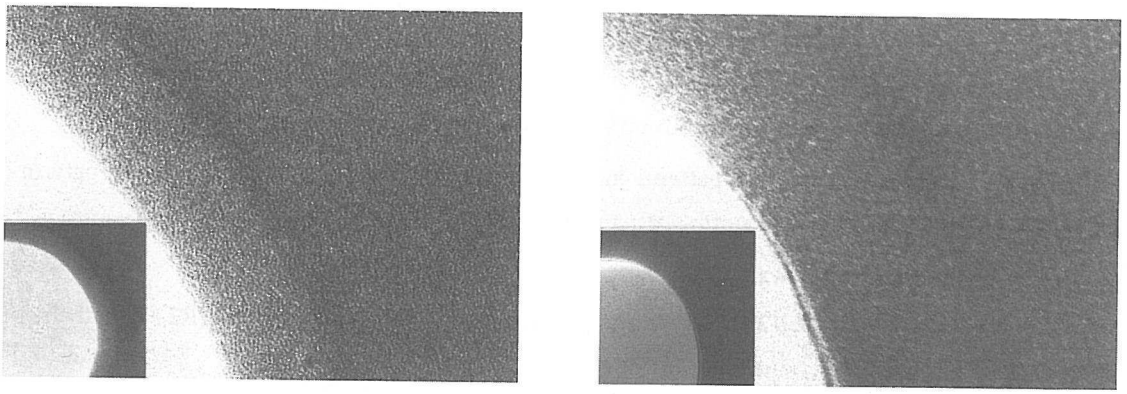
If, when observing diffraction patterns in the S mode illumination system, diffraction pattern (spot) shifts strikingly when the SHIFT-X and/or -Y is(are) turned, adjust the currents in the condenser lens 1st and 2nd beam deflector coils as follows.

1. Turn the α-SELECTOR (L1-20) fully clockwise and set all the S-MODE ADJ (R2-5) to their midway position.
2. Turn the illumination system into the S mode and converge the electron beam to the 1 cm dia. at 10,000 times.
3. Turn on the WOBBLER-IMAGE X or Y (R1-4) and obtain a single illumination spot with the OBJ FOCUS (R1-3).
4. Turn the illumination system into the L mode, depress the SA MAG (R1-8) and turn the BRIGHTNESS (L1-14) fully clockwise.
5. Place the medium-sized field limiting aperture in the beam path.
6. Depress the DIFF (R1-8) and set the camera length to 20 ~ 200 cm with the SELECTOR (R1-9).
7. Sharpen the diffraction pattern (spot) with the DIFF FOCUS (R1-10).
8. Turn the illumination system into the S mode and sharpen the diffraction pattern (spot) with the BRIGHTNESS (L1-14).
9. Adjust the S-MODE ADJ-SHIFT (R2-5) so that the diffraction pattern (spot) does not shift when the SHIFT-X and Y (L1-16, R1-1) are turned.

5.5 Conditions for high magnification/high resolution microscopy

A. The voltage center must be properly aligned.

Fig. 5.5-1a shows a hole image when the voltage center is properly aligned. In this figure, the background structure (phase contrast) is readily discernible, and the edge of the hole can be clearly observed all the way round. On the other hand, Fig. 5.5-1b shows a hole image when the voltage center is misaligned. In this figure, the image is indistinct, the background structure appears unidirectional, and the edge of the hole is blurred as if astigmatism exists.



a: Hole image when voltage center is aligned

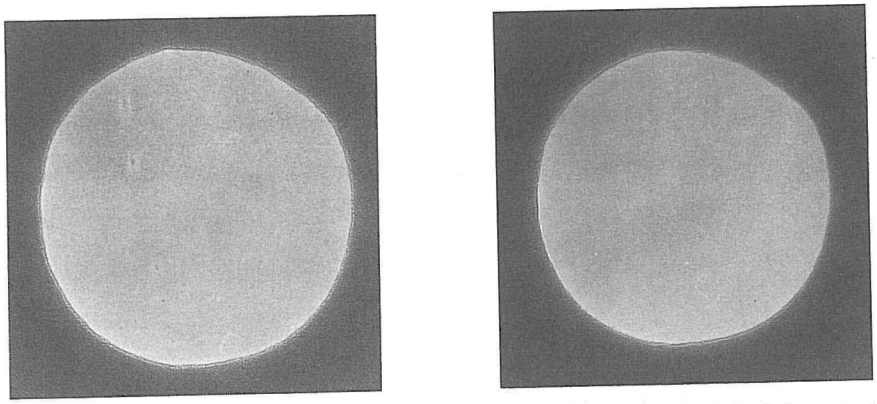
b: Hole image when voltage center is misaligned

Fig. 5.5-1 Effect of voltage center alignment

For high-magnification photography, realign the voltage center at the photographing magnification by using the WOBBLER: HT button switch (R1-4).

B. The objective lens aperture must be properly inserted.

Fig. 5.5-2a shows a hole image when the objective lens aperture is properly inserted into the electron beam path. In this figure, the background structure is readily discernible, and the edge of the hole can be clearly observed all the way round. On the other hand, Fig. 5.5-2b shows a hole image when the aperture is improperly inserted. In this figure, the image is indistinct, the background structure exhibits unidirectional blurring, and the edge of the hole appears as if astigmatism exists.



a: Hole image when aperture is properly inserted into beam path

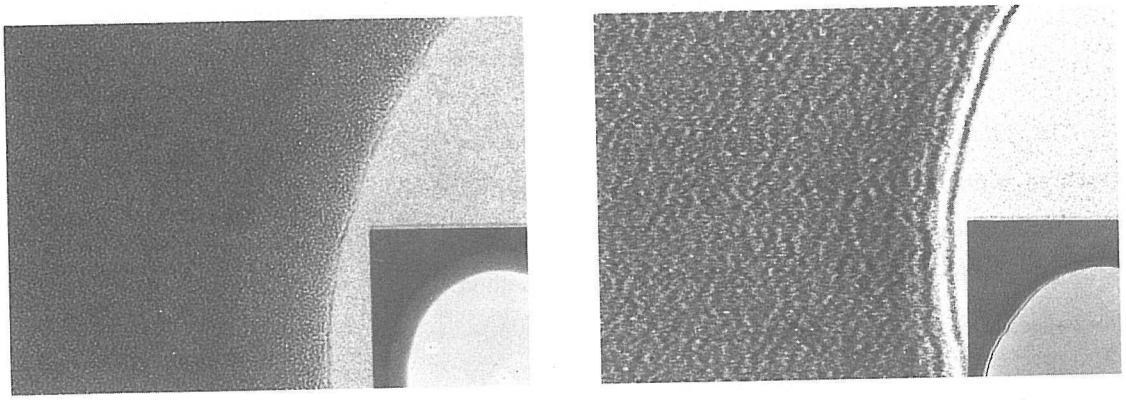
b: Hole image when aperture is improperly inserted into beam path

Fig. 5.5-2 Effect of objective lens aperture insertion

C. The objective lens astigmatism correction must be complete.

If astigmatism exists in the objective lens, the focusing becomes unidirectional, and it will be impossible to focus the image correctly in all directions. To illustrate the point, Fig. 5.5-3a shows a hole image when the lens is free from astigmatism, and Fig. 5.5-3b shows the same image when lens astigmatism is present. It will be seen that when the lens is free from astigmatism, the background structure is clear and the edge of the hole can be readily observed all the way round; and that when lens astigmatism is present, the image is blurred and the Fresnel fringe is asymmetrical around the edge of the hole.

Astigmatism correction should be carried out at a magnification higher than that used for actual photography. However, once astigmatism correction is complete, photography can be carried out at lower magnifications without the need to repeat astigmatism correction. If the amount and direction of astigmatism vary as



a: Hole image when astigmatism does not exist

b: Hole image when astigmatism exists

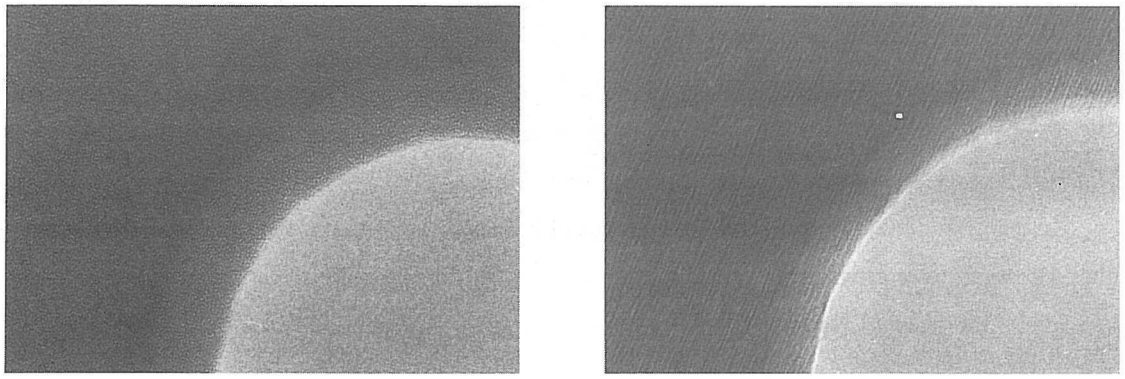
Fig. 5.5-3 Effect of objective lens astigmatism

time goes by, a dirty objective lens aperture or dirty specimen holder is indicated. In this case, clean the contaminated part/parts as per Chap. 6.

Utilizing the background structure in conjunction with the Fresnel fringe (at slightly overfocus) is extremely effective when correcting objective lens astigmatism at magnifications of 100,000X or more. That is to say, after first of all removing the astigmatism as much as possible using the Fresnel fringe, focus the image and then remove any remaining astigmatism so as to make the background structure as clear as possible.

D. The specimen must be tightly secured.

If the specimen is not tightly secured, it will result as time passes in a gradual shift of the specimen (image). This phenomenon is referred to as "image drift". Fig. 5.5-4a shows a hole image under drift-free conditions, and Fig. 5.5-4b shows the same image when image drift exists. In the former, the background structure is distinct, and the edge of the hole can be clearly discerned all the way round. In the latter case, the background structure appears to be unidirectional, and the edge of the hole exhibits one-way blurring.



a: Hole image when there is no drift　　b: Hole image when there is drift

Fig. 5.5-4 Effect of image drift

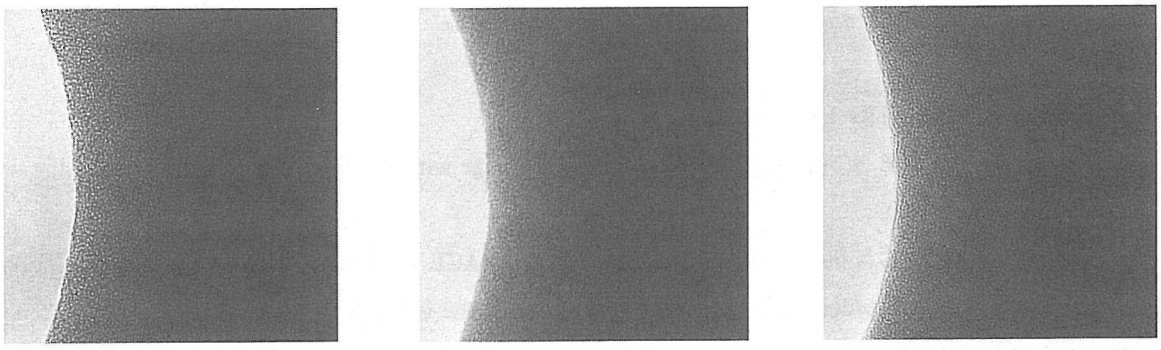
The chief causes of image drift and the countermeasures to be taken are as follows:

- Damaged, wrinkled, improperly secured and/or insufficiently strong supporting film
  Exercise great care when preparing the supporting film. Use adequate adhesive when securing the film to the grid, and reinforce the film using the carbon coating method.
- Bent specimen grid
  Discard and replace with new (unbent) grid.
- Electrically charged specimen and/or supporting film
  Enhance conductivity by coating the specimen and/or supporting film with carbon.

E. The image must be properly focused.

Utilizing the background structure in conjunction with the Fresnel fringe (overfocus or underfocus) is very effective for increasing the focusing accuracy when focusing images at magnifications of 100,000X or more. That is to say, focus the image as precisely as possible with the fringe at underfocus, and then finely focus the image (in-focus) so as to minimize background structure contrast. A further point to keep in mind when focusing images at high magnifications is that, since the possibility of mistaking the apparent fine structure for the actual structure is large, it is necessary to photograph several images while changing the focus very slightly (through-focus method) and to select the optimum-focus image from among the ones photographed (see Sect. 5.6).

Fig. 5.5-5 shows micrographs of perforated film obtained by the through-focus method. These micrographs clearly indicate that the background structure varies according to defocusing (Fresnel fringe variation).



a: Underfocus b: In-focus c: Overfocus

Fig. 5.5-5 Fresnel fringe and background structure variation

F. Others

If the specimen is contaminated, it is difficult to focus the image correctly, and photographs obtained will be obscure even though the image is properly focused. In order to prevent contamination by the electron beam, avoid irradiating the specimen for a long time.

Do not use a magnification higher than that necessary for resolving the feature of interest adequately, and photograph the image with an exposure time as short as possible (two to four seconds will be adequate). If the apertures are contaminated, they may cause astigmatism. Clean them periodically as per Chap. 6.

5.6 Special observations

5.6.1 Low magnification images

1. Carry out column alignment.
2. Remove the objective and field limiting apertures from the electron beam path.
3. Depress the LOW MAG button (R1-8), and spread the electron beam with the BRIGHTNESS knob (L1-14).
4. Select the desired magnification with the SELECTOR switch (R1-9). The selected magnification is displayed on PAGE-1 on the CRT.
5. Align the voltage center.
   5a. Depress the WOBBLER: HT button (R1-4) and BRIGHT TILT button (L1-15).
   5b. Align the voltage center with the DEF: X and Y knobs (L1-17, R1-2).
   5c. Release the WOBBLER: HT button (R1-4) and BRIGHT TILT button (L1-15).
   Note: When the BRIGHT TILT button switch (L1-15) is off, manipulation of the DEF: X and Y knobs (L1-17, R1-2) does not affect the voltage center.
6. Check astigmatism.
   6a. Depress the OBJ STIG 1 button (L1-15).
   6b. Depress the IMAGE X button (R1-4) and focus the image with the OBJ FOCUS knobs (focusing with the image wobbler).
   6c. Release the IMAGE X button (R1-4), and depress the IMAGE Y button (R1-4). If the image is doubled, carry out Step 7 in order to correct the astigmatism. If the image is not doubled, proceed to Step 8.
7. Correct the astigmatism.
   7a. Manipulate the DEF: Y knob (R1-2) so that the double image which appears when the IMAGE Y button (R1-4) is depressed becomes a single stationary image.
   7b. Manipulate the DEF: X knob (L1-17) so that the double image which appears when the IMAGE X button (R1-4) is depressed becomes a single stationary image.
   7c. Repeat Steps 7a and 7b until the image appears as a single stationary image in both Steps 7a and 7b.
8. Release the OBJ STIG 1 button (L1-15) and IMAGE X and Y buttons (R1-4).
   Note: When the OBJ STIG 1 button (L1-15) is released, manipulation of the DEF: X and Y knobs (L1-17, R1-2) does not affect astigmatism.
9. To heighten image contrast, insert a field limiting aperture into the electron beam path.
   9a. Reduce the magnification with the SELECTOR switch (R1-9).
   9b. Set the field limiting aperture assembly lever to the left side. If the illumination disappears from the fluorescent screen, manipulate knobs 2 and 3 so as to align the aperture (see Fig. 5.6-1).

9c. Select the desired aperture size with knob 1.

9d. Correctly align the aperture with knobs 2 and 3.

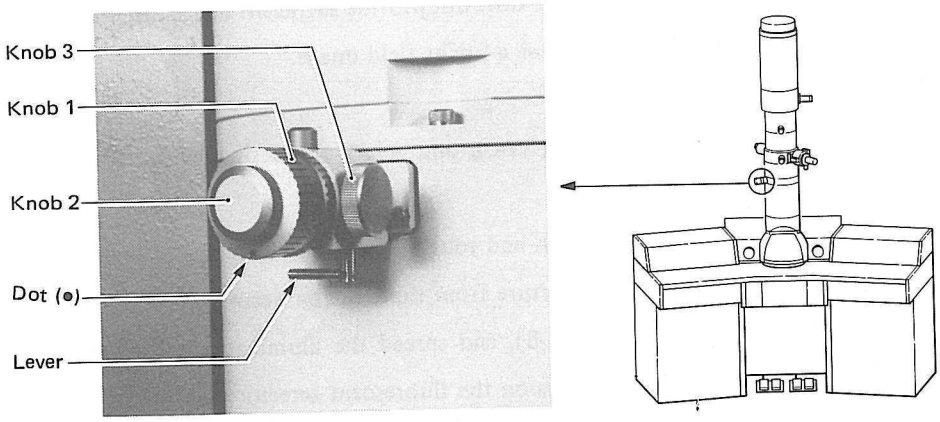
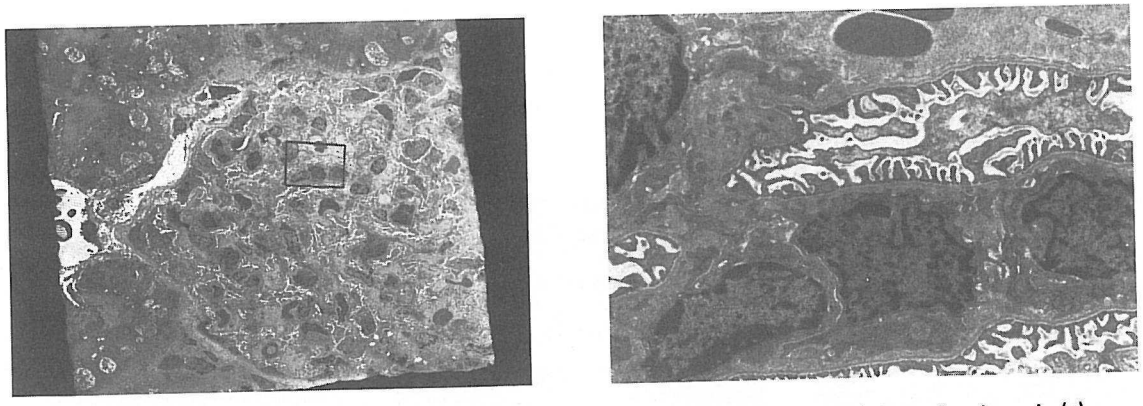


Fig. 5.6-1 Field limiting aperture assembly

10. Focus the image with the image wobbler, and photograph the image.

Note: Photograph the image with the small fluorescent screen inserted into the beam path since the exposure meter does not operate properly when the large fluorescent screen is not illuminated entirely.



a: Low magnification image

b: Enlarged image of the enclosed area in (a)

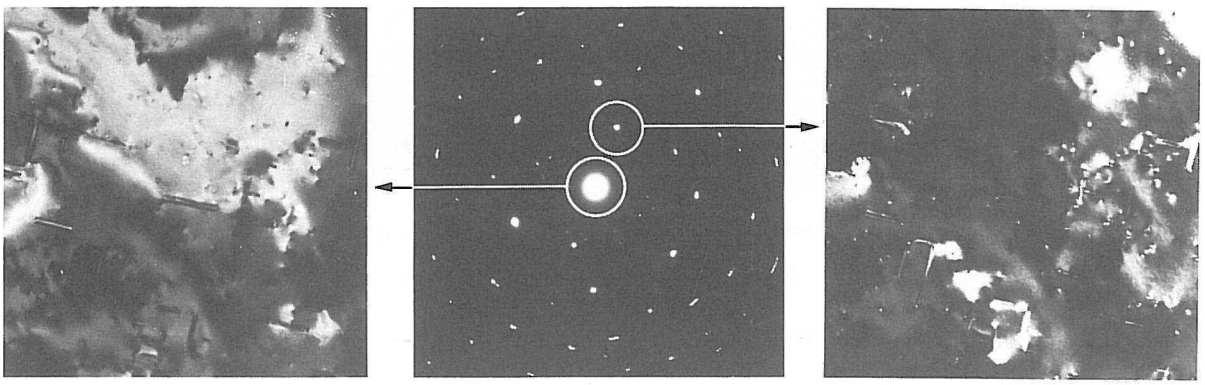
Fig. 5.6-2 Low magnification image

5.6.2 Dark field images

When the incident electron beam passes through the specimen, it splits chiefly into unscattered electron beam and scattered (diffracted) electron beam; the former forms a bright field image, and the latter a dark field image. Though the dark field image does not provide sufficient image brightness, it has an advantage that image contrast is much greater than that of a bright field image.

1. Carry out column alignment.
2. Depress the MAG 1 button (R1-8), and select the desired magnification with the SELECTOR switch (R1-9).
3. Select the desired field of view, and roughly focus the image.
4. Remove the objective lens aperture from the electron beam path.
5. Depress the DIFF button (R1-8), and spread the illumination with the BRIGHTNESS knob (L1-14). A diffraction pattern now appears on the fluorescent screen.
6. Set the camera length to a value between 44 and 130 cm with the SELECTOR switch (R1-9). (The selected camera length is displayed on PAGE-1 on the CRT.)
7. Manipulate the DIFF FOCUS knob (R1-10) so as to obtain the sharpest possible diffraction pattern.
8. Manipulate the PROJ ALIGN knobs (R2-3) so as to precisely center the direct spot on the fluorescent screen.

   Note: The bright spot at the center of the diffraction pattern is referred to as the direct spot.
9. Depress the DARK TILT button (L1-15), and then set the DEF: X and Y knobs (L1-17, R1-2) to the midway position.
10. Manipulate the DEF: X and Y knobs (L1-17, R1-2) so as to precisely center the desired spot on the fluorescent screen. If the illumination shifts when moving the diffraction pattern, recenter it with the SHIFT: X



a: Bright field image **b: Diffraction pattern (aperture position)** **C: Dark field image**

Fig. 5.6-3 Comparison of bright and dark field images

and Y knobs (L1-16, R1-1).

11. Insert the objective lens aperture into the electron beam path, and precisely align the aperture center with the screen center. The aperture image can be focused with the DIFF FOCUS knob (R1-10).
12. Depress the MAG 1 button (R1-8). A dark field image now appears on the fluorescent screen. A bright field image can be obtained by simply depressing the BRIGHT TILT button (L1-15).

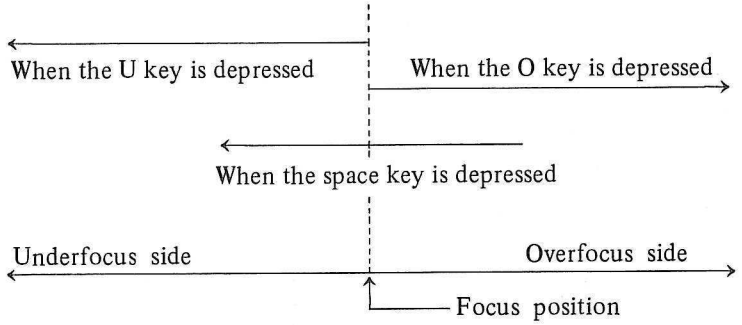
5.6.3 Through-focus method

This is a method to take several photographs by changing the focus very slightly. The through-focus photography is automatically carried out in accordance with the number of films to be exposed and the focus step per film as input through the keyboard.

1. Switch off the OBJ 16X button (R1-3).
2. In the case of automatic exposure, switch on the SHUTTER AUTO button (R1-6). In the case of manual exposure, switch off the SHUTTER AUTO button (R1-6) and set the exposure time.
3. Input the number of films to be exposed and the amount of focus change per film.

3a. Depress the THRU FOCUS key (KB-1). "TF N =" and "ΔF = Δ*" are displayed in the bottom margin of PAGE-1.

3b. Depress the U, O or space key (KB-2) between the TF and N. When the U, O or space key is depressed, focus changes as follows:



3c. Write the number of films to be exposed (up to 50) and the amount of focus change (1 to 9) in the space after "N =" and "Δ*", respectively (see Subsect. 5.2.11f). If the number of films to be exposed exceeds the number of unused films, set additional films as required in the dispensing magazine.

Notes: *1. The number of unused films is displayed on PAGE-1.*

2. The amount of focus change (1 to 9) indicates the number of OBJ FOCUS: FINE knob (R1-3) knotches.

3d. Depress the RETURN key (KB-2). If "ERROR" appears in the bottom margin, restart from Step 3a.

4. Depress the THRU FOCUS key (KB-1) again.
5. Focus the image.

6. After confirming that there is sufficient room in the receiving magazine, depress the PHOTO button (L1-12).

5.6.4 Minimum exposure operation (MDS)

This is photographing with minimum exposure in order to reduce specimen damage due to electron irradiation. Specimen damage occurs mostly during image focusing when photographing in the general way. In the MDS mode, specimen damage is much smaller because the focusing is carried out outside the field to be photographed.

This system is composed of three modes, SEARCH, FOCUS and PHOTO. The electron beam diverges in the SEARCH mode and converges to a position, away from the field of view to be studied in the FOCUS mode. In the PHOTO mode, photographing is performed with the magnification, brightness and exposure time stored beforehand. The various conditions, such as magnification and brightness, in each mode can be set individually. It is possible to use the through-focus mode together with the MDS.

1. Depress [M][D][S][RETURN] . The MDS is switched on and the CRT displays the PHOTO MODE (Fig. 5.6-4).

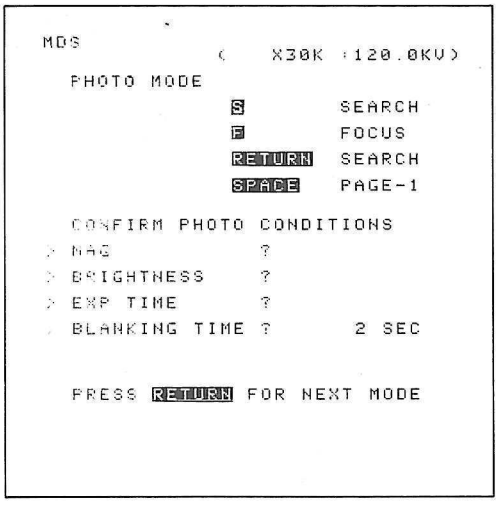


Fig. 5.6-4 PHOTO MODE

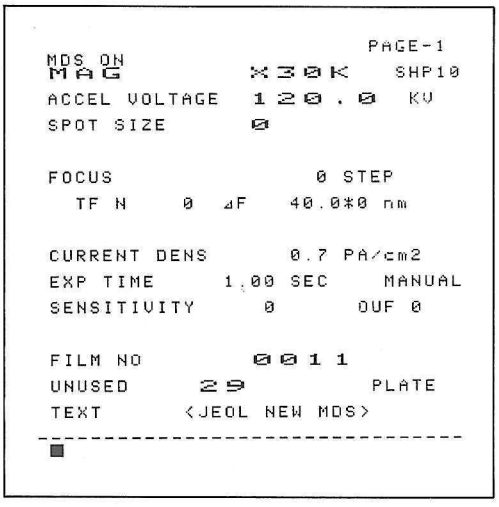


Fig. 5.6-5 PAGE-1 (MDS ON)

2. Set conditions in the PHOTO MODE.

2a. Set the magnification and image brightness to those for photographing.

2b. Display PAGE-1 on the CRT by depressing the space key (KB-2).

Note: Each time the space key is depressed, the CRT displays PAGE-1 and the original mode (PHOTO MODE in this case) alternately. In this case, "MDS ON" appears in the upper left corner of PAGE-1 (Fig. 5.6-5).

2c. Select the exposure time for photographing the specimen to be studied and store it.

2d. Display the PHOTO MODE with the space key.

2e. Enter the desired blanking time through the key board (0 to 99 sec).

Note: When photographing in the MDS mode, the electron beam is cut off for a certain period just before the shutter opens, in order to minimize specimen drift due to heat imbalance by electron beam irradiation. This period in which the electron beam is cut off is called a "blanking time".

2f. Depress the RETURN or S key (KB-2). The next mode (SEARCH MODE, Fig. 5.6-6) appears.

3. Set conditions in the SEARCH MODE.

3a. Set the magnification and image brightness to those for searching the desired field of view.

Note: The brightness should be the minimum at which the image is still discernible.

3b. Enter the desired MDS mode (FOCUS MODE or SEARCH MODE), which is automatically set up after photographing, with the N key (KB-2). Each time the N key is depressed, "FOCUS MODE" and "SEARCH MODE" appear alternately on the "AFTER PHOTO?" line (Fig. 5.6-6).

3c. Depress RETURN or F (KB-2). The next mode (FOCUS MODE, Fig. 5.6-7) appears.

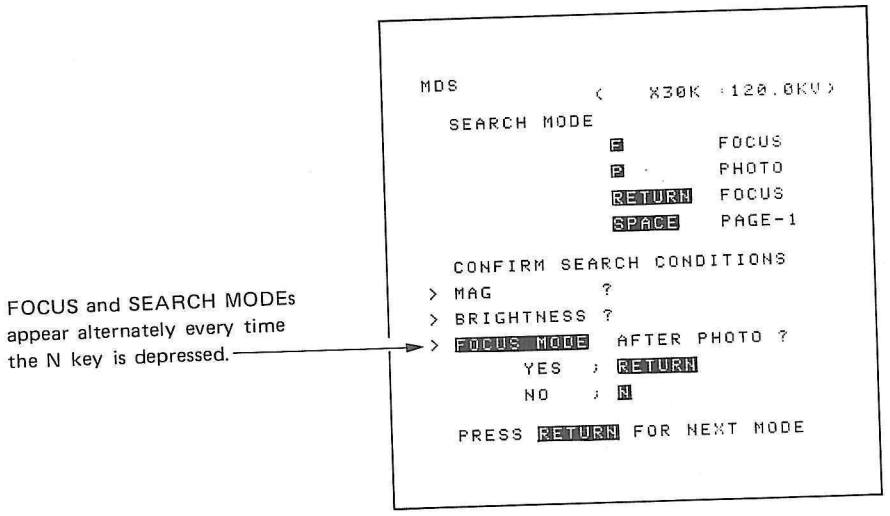


Fig. 5.6-6 SEARCH MODE

4. Set conditions in the FOCUS MODE.

4a. Set the magnification to that for focusing.

4b. Bring a conspicuous image to the screen center with the specimen shift knobs.

4c. Shift the conspicuous image out of the fluorescent screen with the left and right DEFs (L1-17, R1-2).

4d. Obtain the smallest electron beam and center it with the left and right SHIFTs (L1-16, R1-1).

4c. Set the image brightness to that for focusing.

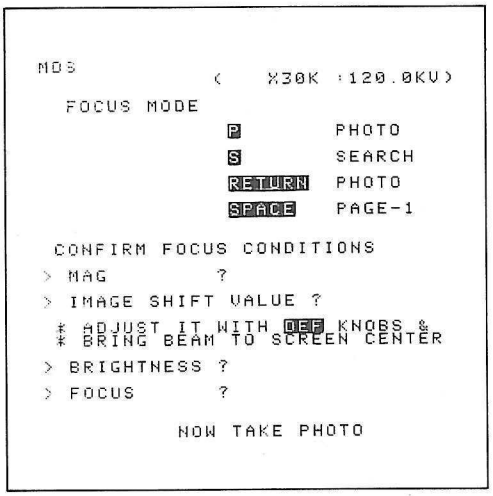


Fig. 5.6-7 FOCUS MODE

5. Take a picture of the specimen to be studied.

5a. Depress the S key (KB-2) to display the SEARCH MODE and insert a specimen to be studied.

5b. Bring the desired field of view to the screen center with the specimen shift knobs.

5c. Depress the RETURN or F key (KB-2) to display the FOCUS MODE and carry out astigmatism correction and focusing.

5d. Depress the PHOTO button (L1-12) for photographing.

6. To complete the MDS operation, obtain PAGE-1 with the space key, then depress again [M][D][S] [RETURN] .

5.6.5 Using the BRIGHT ZOOM system

The change in image brightness when the magnification is varied is reduced to the minimum by using the BRIGHT ZOOM system.

1. Turn off the BRIGHTZOOM and BRIGHT 16X switches (L1-10, 11).
2. Turn on the MAG1, MAG2 or SAM/ROCK switch (R1-8).
3. Turn on the SHUTTER AUTO switch (R1-6).
4. Make the electron beam as small as possible with the BRIGHTNESS knob (L1-14), then obtain the desired image brightness by turning the knob clockwise.
5. Turn on the BRIGHT ZOOM switch (L1-10).

Notes: *1. When the magnification is varied sharply, several seconds may pass before the zooming circuit is in full operation.*

2. When the magnification is too high or too low, weak peep sounds will be heard. Then, start again from Step 1.

3. Begin from Step 1 when the field of view is changed.

5.6.6 Micro-area analysis mode

In this mode, analyses in a micro-area can be performed while observing a transmitted image.

1. Carry out column alignment according to Subsect. 5.3.
2. Insert the condenser lens aperture of 40 or 70 μm in dia. and select the desired spot size. The spot sizes when the condenser lens aperture of 40 μm in dia. is used are as follows.

SPOT SIZE number	L mode	S mode
1	500 nm in dia.	40 nm in dia.
2	300	20
3	200	10
4	100	6
5	40	4
6	20	2

3. Turn off the S button (L1-19), set the magnification to 50,000 times or more, and bring the desired field of view to be analyzed to the screen center.
4. Turn on the S button (L1-19) and bring the electron beam to the field of view with the left and right SHIFT knobs (L1-16, R1-1).

5.7 Electron diffraction

This section describes three diffraction methods: selected area electron diffraction, microbeam electron diffraction, and high dispersion electron diffraction. Refer to the EM-AD instruction manual for high resolution electron diffraction.

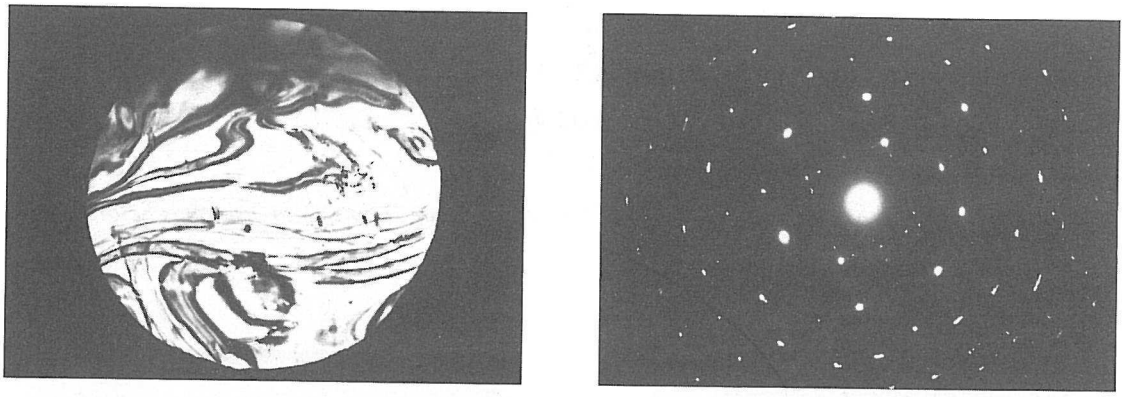
5.7.1 Selected area electron diffraction

In this method, a diffraction pattern is formed by the electron beam passing through a small area limited by the intermediate lens aperture.

1. Carry out column alignment, and insert the specimen into the electron beam path.
2. Depress the DIFF button (R1-8), and set the camera length to 270 cm with the SELECTOR switch (R1-9).
   Note: The camera length is displayed on the DIFF line on PAGE-1.
3. Manipulate the DIFF FOCUS knob (R1-10) so as to obtain the sharpest possible direct spot. If the spot is not at the center of the fluorescent screen, center the spot with the PROJ ALIGN knobs (R2-3).
4. Insert the field limiting aperture into the electron beam path.
   4a. Set the field limiting aperture assembly lever to the left side. If this causes the image to disappear, reduce the magnification, and manipulate knobs 2 and 3 so as to align the aperture (see Fig. 5.6-1).
   4b. Select the desired aperture size with knob 1.
   4c. Focus the field limiting aperture image with the DIFF FOCUS knob (R1-10).
   4d. Center the aperture image with knobs 2 and 3.
5. Depress the SAM/ROCK button (R1-8) and select the desired field of view and magnification.
6. If necessary, record the image (selected area image, Fig. 5.7-1).
7. Remove the objective lens aperture from the electron beam path.
8. Depress the DIFF button (R1-8), and select the camera length between 13 cm and 270 cm with the SELECTOR switch (R1-9).
   Note: The camera lengths that can be switched are 13 to 270 cm, 400 cm to 80 m, and 33.7 cm. The 13 cm to 270 cm camera lengths are for selected area electron diffraction, the 400 cm to 80 m camera lengths for high dispersion electron diffraction, and the 33.7 cm camera length is for high resolution electron diffraction.
9. Focus the diffraction pattern with the DIFF FOCUS knob (R1-10).
10. Block the direct beam with the beam stopper knob (option).
11. Darken the diffraction pattern with the BRIGHTNESS knob (L1-14) to the extent that the pattern is just

discernible on the fluorescent screen, and record the pattern by manual exposure. An exposure time of about 1 minute is recommended.

Note: If the direct spot is also to be recorded, remove the beam stopper 1 to 2 seconds before completing the exposure.



a: Selected area image

b: Selected area diffraction pattern

Fig. 5.7-1 Selected area electron diffraction

5.7.2 Microbeam electron diffraction

In this method, a diffraction pattern is formed by the finely converged electron beam illuminating only a very small area on the specimen.

1. Carry out column alignment, and insert the specimen into the electron beam path.
2. Depress the DIFF button (R1-8), and set the camera length to 270 cm with the SELECTOR switch (R1-9).
   Note: The camera length is displayed on the DIFF line on PAGE-1.
3. Manipulate the DIFF FOCUS knob (R1-10) so as to obtain the sharpest possible direct spot. If the spot is not at the screen center, center the spot with the PROJ ALIGN knobs (R2-3).
4. Depress the MAG 1 button (R1-8), and select a magnification between 3,400X and 410,000X.
5. Precisely center the feature of interest, and focus the image.
6. Record the image (first one of double exposure) as described in Sect. 5.4.4c (multiple exposure).
7. Remove the objective lens aperture from the electron beam path, and select the smallest condenser lens aperture.
8. Minimize the spot size with the SPOT SIZE switch (L1-8), and converge the electron beam with the BRIGHTNESS knob (L1-14).
9. Center the converged electron beam with the SHIFT: X and Y knobs (L1-16, R1-1). This aligns the converged beam with the feature of interest.

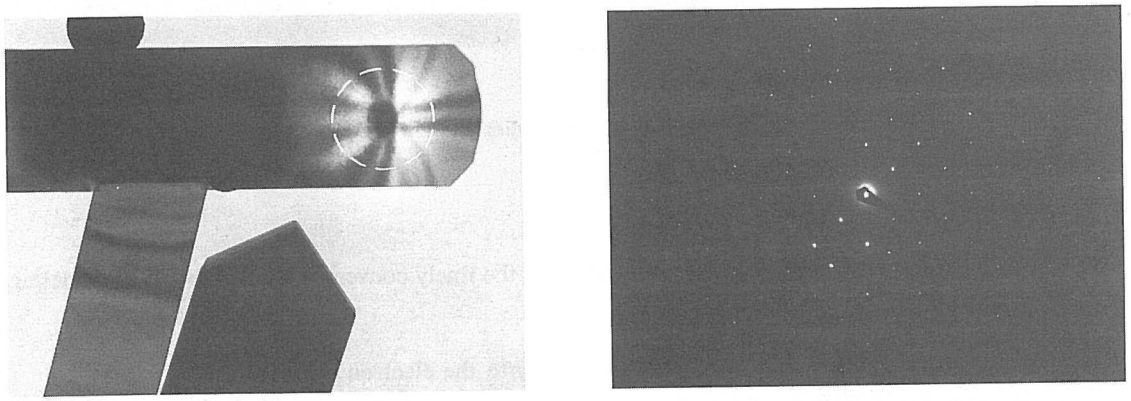
Caution: After this step, do not turn the SHIFT: X, Y and BRIGHTNESS knobs, and do not shift the specimen.

10. Record the beam spot (second one of double exposure) in accordance with Sect. 5.4.4c (multiple exposure).

    Note: By the first exposure (Step 6), the whole field of view is photographed and by the second, the beam spot in the feature of interest is photographed on the same film (Fig. 5.7-2a).

11. Depress the DIFF button (R1-8), and set the camera length to 13 cm with the SELECTOR switch (R1-9).
12. Focus the diffraction pattern with the DIFF FOCUS knob (R1-10).
13. Block the direct beam with the beam stopper knob (optional).
14. Record the diffraction pattern by manual exposure.

    Note: If the direct spot also is to be recorded, remove the beam stopper 1 to 2 seconds before completing the exposure.



a: Beam spot and image

b: Microbeam diffraction pattern

Fig. 5.7-2 Microbeam electron diffraction

5.7.3 High dispersion electorn diffraction

The maximum lattice spacing that can be analyzed by the selected area diffraction method is on the order of tens of Ångstroms. This can be extended, however, to several thousand Ångstroms by means of the high dispersion diffraction method. However, since the specimen in this method is easily charged, coat the specimen on both sides with carbon if specimen conductivity is very low.

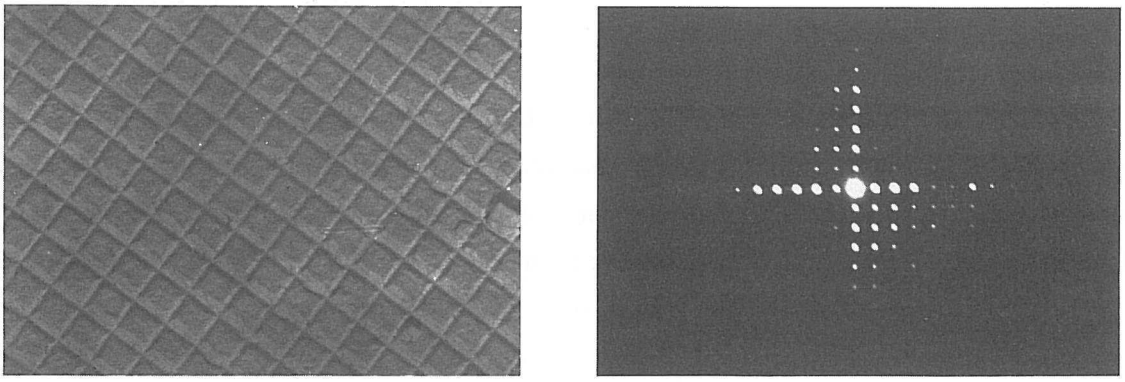
1. Carry out column alignment, and insert the specimen into the electron beam path.
2. Depress the MAG 1 button (R1-8), and select the desired magnification.
3. Select the desired field of view, and record the image.
4. Depress the LOW MAG button (R1-8), obtain a magnification of about 500X, and focus the image.
5. Spread the electron beam over the field of view with the BRIGHTNESS knob (L1-14), and bring the

desired feature to the fluorescent screen center.

6. Select the small objective lens aperture, and align the center of the aperture image with the fluorescent screen center.
7. If necessary, record the image.
8. Depress the DIFF button (R1-8), and obtain a camera length of 400 cm or longer with the SELECTOR switch (R1-9).

   Note: The camera lengths that can be switched are 13 to 270 cm, 400 cm to 80 m, and 33.7 cm. The 33.7 cm camera length is for high resolution electron diffraction, the 13 cm to 270 cm camera lengths are for selected area electron diffraction, and the 400 cm and longer camera lengths for high dispersion electron diffraction.

9. Focus the direct spot with the DIFF FOCUS knob (R1-10). If the direct spot is not on the fluorescent screen, turn the BRIGHTNESS knob (L1-14) counterclockwise to find the direct spot, center it with the SHIFT X and Y knobs (L1-16, R1-1), repress the DIFF button (R1-8) and focus it with the DIFF FOCUS knob (R1-10).
10. Record the diffraction pattern by manual exposure.



a: Micrograph of optical replica **b: Corresponding high dispersion diffraction pattern**

Fig. 5.7-3 High dispersion electron diffraction

5.7.4 Convergent beam electron diffraction

In this method, the electron beam is sharply demagnified by the prefield of the objective lens, and irradiates the specimen with large convergent angle. The convergent angle can be changed with the irradiated area kept unchanged in size by employing a condenser mini-lens. This method is useful to examine the crystallographic symmetry in an extremely fine area.

1. Carry out column alignment according to Subsect. 5.3.

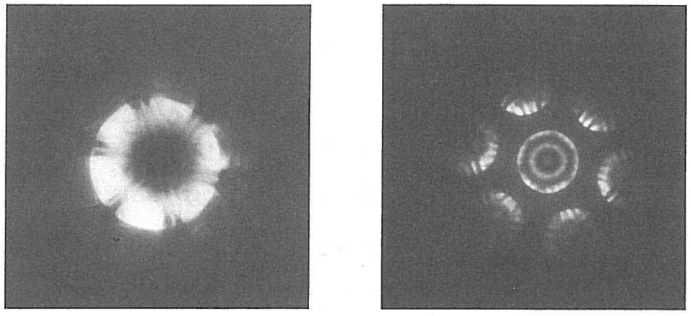
   Note: A condenser lens aperture of 40 or 70 μm in dia. is recommended.
2. Turn off the S button (L1-19) and turn on the SAM/ROCK button (R1-8).
3. Set the magnification to 50,000 times or more and bring the desired field of view, from where convergent beam electron diffraction pattern is expected, to the screen center.
4. Confirm that the CM button (L1-18) is turned on and turn on the S button (L1-19).
5. Converge the electron beam in the area from where convergent beam electron diffraction pattern is expected.
6. Turn on the DIFF button (R1-8) and remove the objective and field limiting apertures from the beam path. A convergent beam electron diffraction pattern now appears on the screen.
7. Tilt the specimen (see Subsect. 5.8) to obtain the desired diffraction pattern. If necessary, center the pattern with the PROJ ALIGN knobs (R2-3) and select the convergent angle with the α-SELECTOR knob (L1-20).

In the convergent beam electron diffraction (CBED) method, a cone-shaped electron beam with convergent angle of 10^{-2} rad or more irradiates the specimen. A diffraction pattern is then formed and enlarged as diffraction disks corresponding to the convergent angle of the electron beam. These diffraction disks contain diffraction intensity distribution with characteristic symmetry. The irregularity of the diffraction intensity is due to slight irregularity of electron beam incident angle. The diffraction intensity in this case corresponds to that obtained by calculation using dynamic diffraction theory.

This diffraction method facilitates examination of crystallographic symmetries in a microarea, which cannot be achieved in the X-ray method. This method is useful to examine the symmetry of entire specimens as well as that of a single lattice because of the symmetry of diffraction patterns. This method is also useful to determine the structural factors of crystals. As a by-application, the CBED is used to accurately measure the thickness of crystals. The pattern in the diffraction disk, viz. zone axis pattern, is used to determine the point group and space group in crystals.

The objective lens in the CBED mode is used as a C-O (condenser-objective) lens since the objective lens prefield produced ahead of the specimen must be very strong to form a CBED pattern. In the C-O lens mode, the convergent angle of the electron beam irradiating the specimen is proportional to the condenser lens aper-

ture diameter. A CBED pattern is formed on the objective lens back focal plane, and a specimen image is produced on the field limiting aperture plane. The pattern or image is then projected on the image plane of the next lens by putting the focal point of the lens to the objective lens back focal plane or field limiting aperture plane. A final image therefore is produced in the same way as the selected area diffraction mode.



Large convergent angle **Small convergent angle**

Fig. 5.7-4 CBED pattern

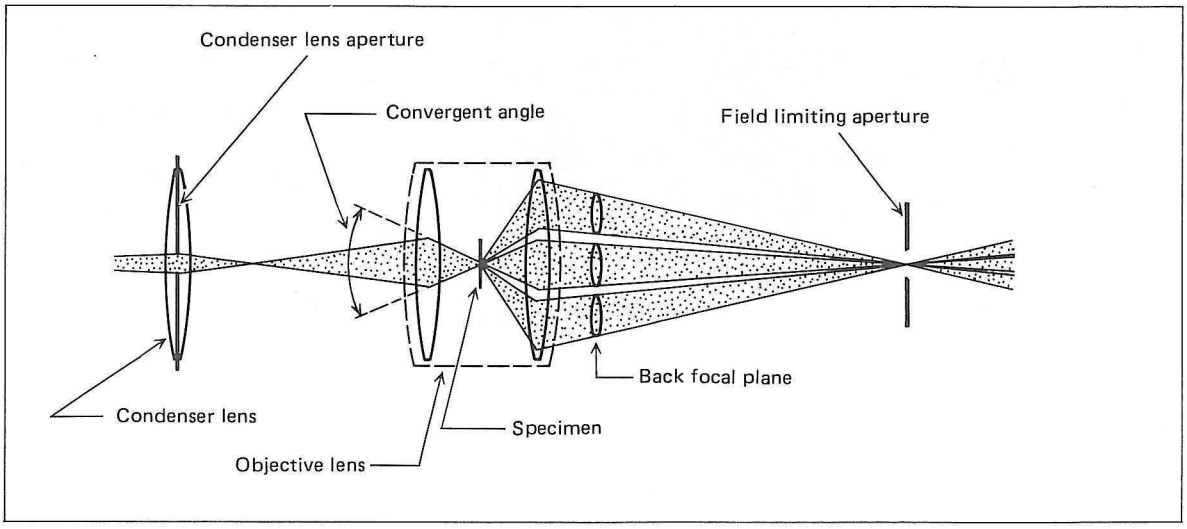


Fig. 5.7-5 CBED ray diagram

5.8 How to use the goniometer

By using the goniometer, the specimen can be freely tilted.

5.8.1 Specimen tilting

1. Select the X-tilting speed with the X-TILT knob (GC-1).
2. Confirm that the lamp (Fig. 5.8-1) is lit.

   Note: If the lamp is not lit, the following step to tilt the specimen cannot be carried out.
3. Tilt the specimen with one of the X pedal switches. If the image shifts more than a little when the specimen is tilted, return the X-tilt angle to 0°, and align the specimen tilt axis as described in Sect. 5.8.2.
4. Read the X-tilt angle on the graduated scale engraved on the X-tilt knob (Fig. 5.8-1).

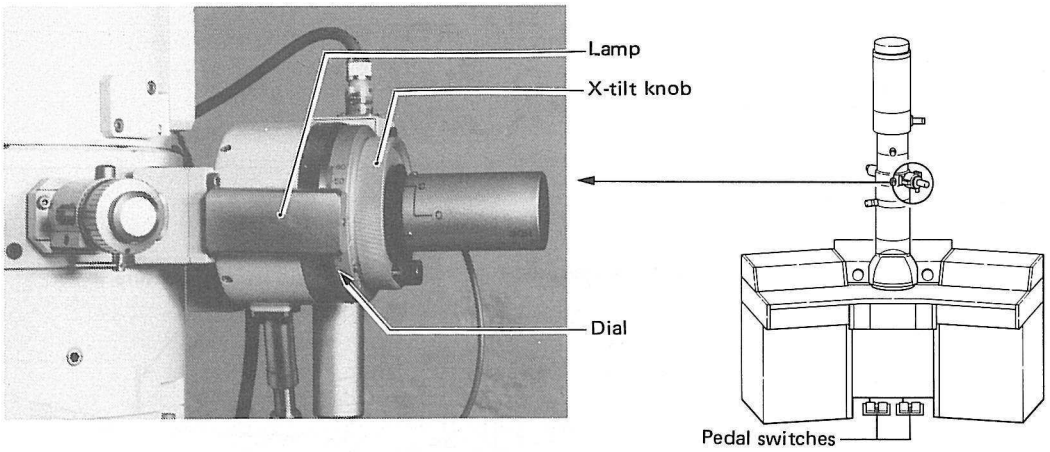


Fig. 5.8-1 X-tilt knob

5.8.2 Tilt axis alignment

The image will not shift when the specimen is tilted so long as the specimen tilt axis accords with the specimen surface and is intersecting the optical axis of the microscope column. If the image shifts when the specimen is tilted, align the tilt axis as follows:

1. Confirm that the X-tilt angle is 0°.
2. Obtain a low magnification image (500X to 600X).
   2a. Depress the LOW MAG button (R1-8).
   2b. Obtain a magnification of from 500X to 600X with the SELECTOR switch (R1-9).
   The magnification is displayed on PAGE-1 on the CRT.
3. Set the left specimen shifting knob to its midway position.
   3a. Make the CRT display PAGE-2.
   3b. Zero the P-X value on PAGE-2 with the left specimen shifting knob.
4. Disengage the motor from the goniometer by pushing the motor (Fig.5.8-2) towards the column rear. The lamp now goes out.

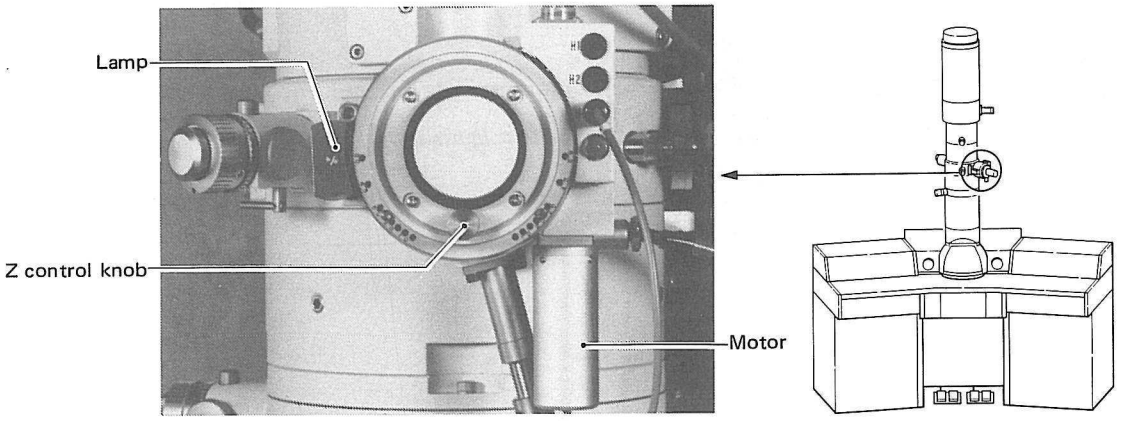


Fig. 5.8-2 Lamp, motor, and Z control knob

5. Turn the X-tilt knob fully counterclockwise.
6. Bring some feature in the image to the screen center with the specimen shifting knobs.
7. After turning the X-tilt knob fully clockwise, note the position of the feature.
8. Position the feature midway between the screen center and the position noted in Step 7 with the Z control knob (Fig. 5.8-2).
9. Repeat Steps 5 to 8 until the position of the feature, with the X-tilt knob turned fully clockwise, coincides with the position of the feature when the knob is turned fully counterclockwise. The tilt axis now accords

with the specimen surface.

10. Adjust the axis alignment screws (Fig. 5.8-3) so that the feature remains stationary when the X-tilt knob is turned. The X-tilt axis now intersects the optical axis of the microscope column.

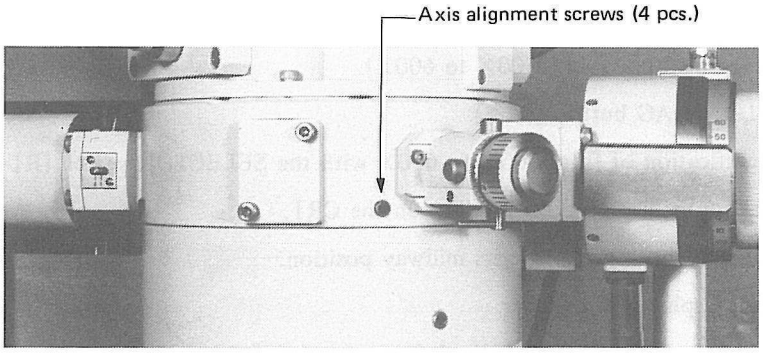


Fig. 5.8-3 Axis alignment screws

11. Carry out Steps 5 to 10 at magnifications of 5,000X and 10,000X.
12. Engage the motor gear and the goniometer gear by pulling the motor (Fig. 5.8-3) to the fullest extent. The goniometer lamp lights up.

    Note: If the motor and goniometer gears are improperly engaged, the lamp fails to light up. In that case, slightly turn the X-tilt knob until the lamp lights up.

5.9 Use of the hoist

The hoist is used to assemble/disassemble the column and to raise the HT tank. The maximum load capacity is 100 kg.

1. Assemble the support (Fig. 5.9-1).
2. Remove the central console left cover (Fig. 5.9-2).
3. Attach brackets A and B to the upper and lower sides of the support mounting position and place the spacer in bracket B (Fig. 5.9-2).
4. Fit the support in the brackets and secure the support with the bracket A lock pin.
5. Suspend the hoist (Fig. 3.2-4).

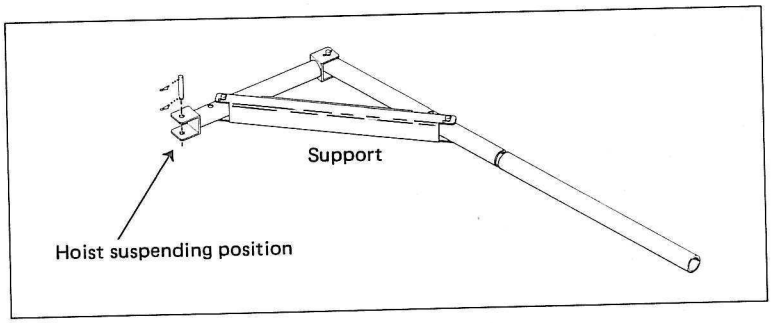


Fig. 5.9-1 Hoist support

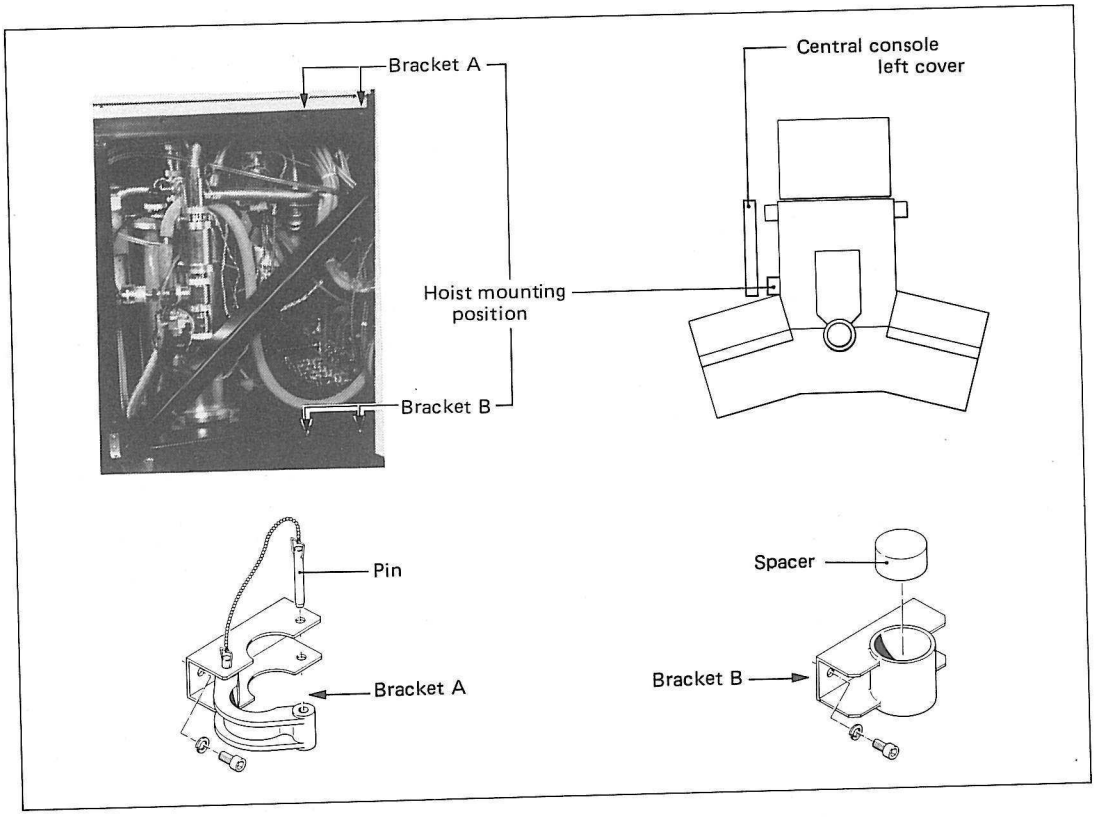


Fig. 5.9-2 Attaching bracket

6. MAINTENANCE

6. MAINTENANCE

This chapter deals mainly with routine and preventive maintenance for ensuring peak instrument performance at all times.

The symbols L1, L2, R1, R2, GC and KB appearing in parentheses after the names of panel controls designate the respective control panels (see Fig. 3.4-1).

6.1 Electron gun filament replacement

6.1.1 Ascertaining the electron gun filament burnout

1. Generate an accelerating voltage.
2. Obtain the maximum BIAS MODE (L1-7) value with the BIAS MODE: COARSE and FINE switches (L1-7).
3. Confirm that valve V3 is open (the valve conditions are displayed on PAGE-3).

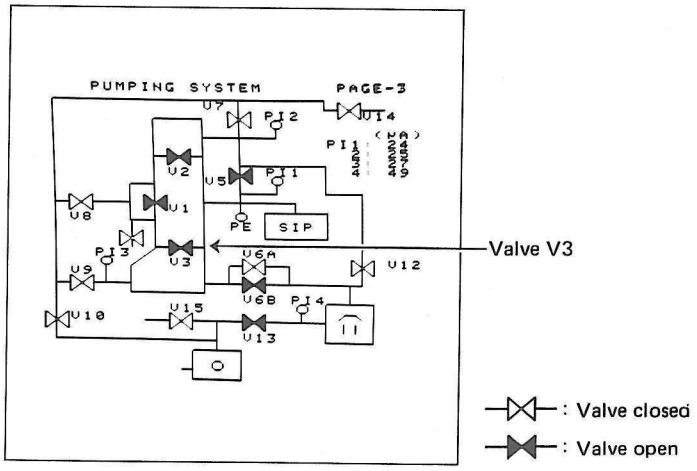


Fig. 6.1-1 PAGE-3

4. Turn the FILAMENT knob (L1-2) fully clockwise, and ascertain that this does not cause the BEAM CURRENT (L1-1) reading to increase.

Note: If the meter reading increases, the filament is not burnt out.

5. Return the BIAS MODE (L1-7) reading to the original value (between 70 and 80), and set the FILAMENT knob (L1-2) stopper at the original position.

6.1.2 Admitting air into the anode chamber

6. Position the FILAMENT knob (L1-2) to OFF, and release the HT button (L1-6).
7. If the lift and anode chamber are connected by flat bars, remove the bars (Fig. 6.1-2).

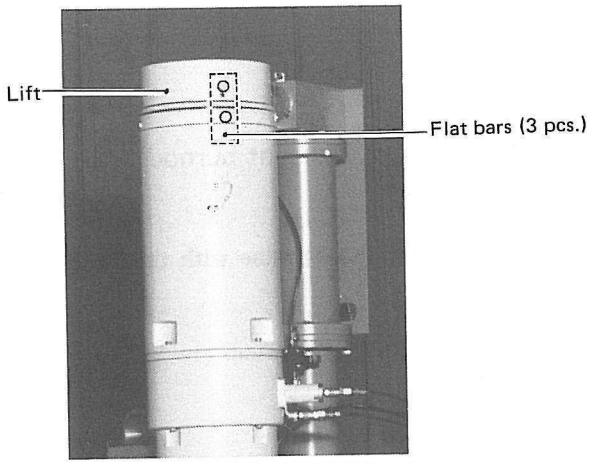


Fig. 6.1-2 Flat bars

8. Depress the GUN AIR button (L2-4). Air is admitted into the anode chamber.
9. Make sure that the PI2 value (indicated on PAGE-3) has increased to 250, then turn the LIFT switch (L2-1) to ON.
10. Cover the anode chamber with aluminum foil or the like to keep out dust.

6.1.3 Filament replacement

Note: This procedure is for a tungsten filament. When an LaB_6 filament is used, see an appropriate instruction manual.

11. Confirm that the grounding device is in contact with the Wehnelt assembly (tip of the electron gun) and wait for the assembly to cool down.

    Caution: The Wehnelt assembly remains hot for some time after the filament has burnt out. Accordingly, allow a few minutes for the assembly to cool down before handling.

12. Remove the cylinder by turning it counterclockwise (Fig. 6.1-3)

    Caution: Be sure to wear clean, cotton or nylon gloves when handling the cylinder, Wehnelt assembly, etc. Dirt, perspiration, etc. from bare hands are a possible cause of high voltage discharge.

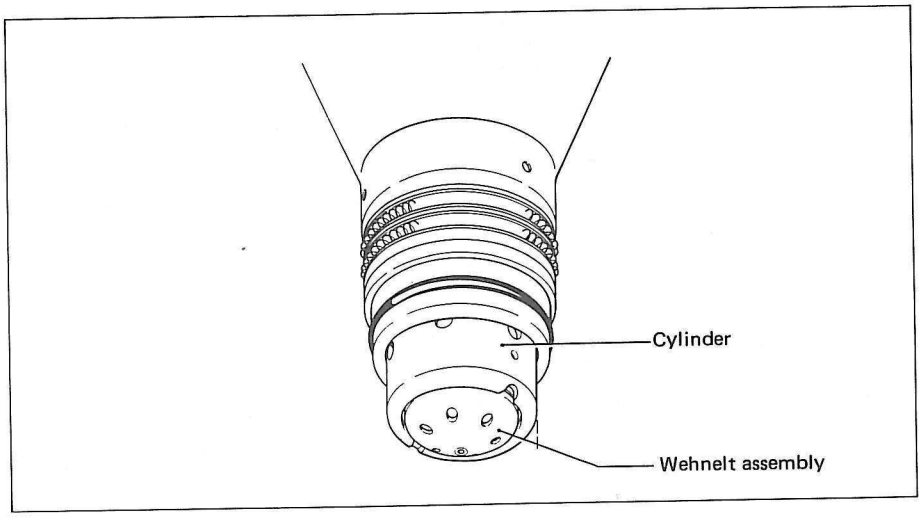


Fig. 6.1-3 Cylinder and Wehnelt assembly

13. Remove the Wehnelt assembly by pulling it downwards.
14. Disassemble the Wehnelt assembly as follows (Fig. 6.1-4):
    14a. Loosen the three filament securing screws with a hex key (Fig. 3.2-2), and remove the burnt-out filament (cathode) from the filament holder.
    14b. Remove the Wehnelt cap (grid) and spring from the filament holder by turning the cap counterclockwise.

    Note: If the cap is difficult to turn by hand, use the Wehnelt adjusting tool (Fig. 3.2-3).

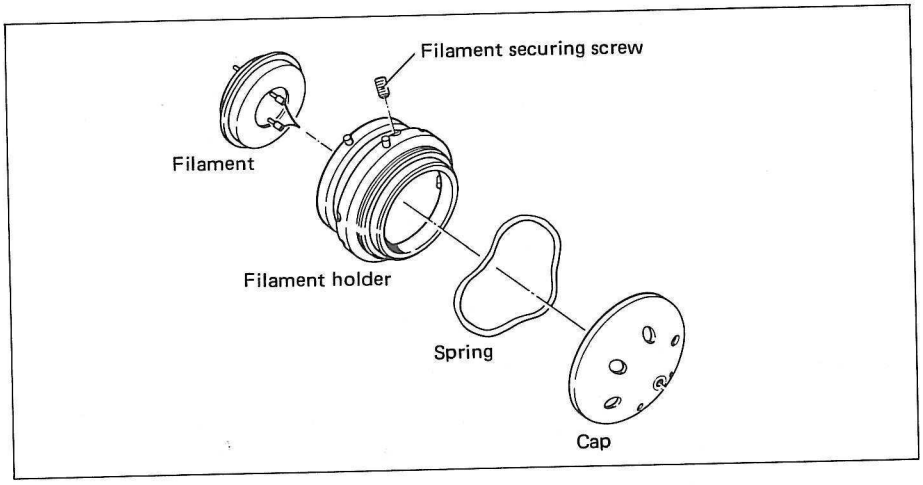


Fig. 6.1-4 Exploded view of Wehnelt assembly

15. Clean the Wehnelt cap (See Sect. 6.4.5a).

16. Attach the spring to the filament holder and screw the cap onto the holder (1 to 2 turns).

    Apply the hand blower (Fig. 3.2-1) to the assembled unit to remove any traces of lint that may still be adhering.

17. Insert a new filament into the holder so that the filament base groove aligns with the holder pin, then secure the filament to the holder with the three filament securing screws.

    Caution: Be very careful not to touch the filament tip.

6.1.4 Adjusting the Wehnelt cap

18. As shown in Fig. 6.1-5, place the assembled Wehnelt on the pedestal of the Wehnelt adjusting tool (Fig. 3.2-3), then fit the Wehnelt adjusting tool cap over the Wehnelt assembly so that the cap pin aligns with one of the holes in the Wehnelt cap.

19. Adjust the position (height) of the Wehnelt cap as follows (Fig. 6.1-5):

    19a. Screw in the Wehnelt cap by turning the Wehnelt adjusting tool cap clockwise until the tip of the Wehnelt cap is flush with the tip of the filament.

    19b. Turn the Wehnelt adjusting tool cap in the counterclockwise direction to make the tip of the Wehnelt cap 0.65 mm higher than the tip of the filament.

    Note: The Wehnelt adjusting tool cap is equipped with a calibrated scale which indicates the amount of cap displacement. Thus, one complete turn of the cap displaces the Wehnelt cap 0.5 mm up or down depending on the turning direction.

    19c. Remove the Wehnelt assembly from the tool.

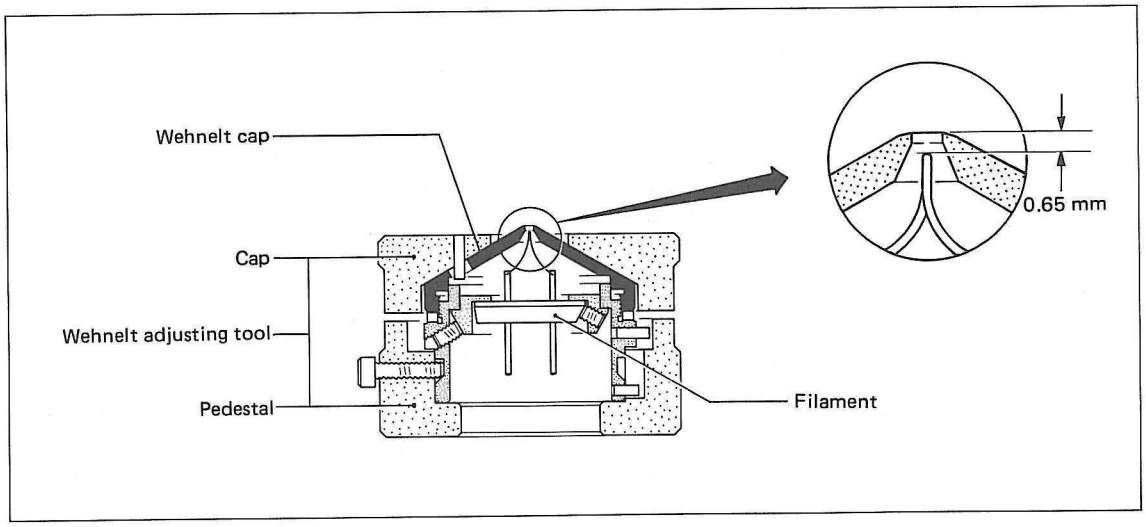


Fig. 6.1-5 Wehnelt cap adjustment

6.1.5 Re-evacuating the anode chamber

20. Mount the Wehnelt assembly in the electron gun socket by aligning the assembly pin with the socket groove, pushing the assembly into the socket as far as it will go, and securing the Wehnelt assembly with the cylinder (Fig. 6.1-6).
21. Apply the hand blower to the electron gun O-ring and Wehnelt assembly to remove all traces of lint, dust, etc. Then, remove the aluminum foil covering the anode chamber and check the interior. Give the interior a good blow out with the hand blower. Lint, etc. remaining in the anode chamber may cause high voltage discharge. Check the O-ring too; a dirty O-ring can cause vacuum deterioration. Flip off lint, etc. with finger from the O-ring (be sure to wear gloves when doing this).
22. Make sure that the entire silicon gum portion of the insulator is coated with silicon grease. If not, smear the provided grease (Subsect. 3.2).
23. Release the GUN AIR button (L2-4). The electron gun now returns to its original position and the anode chamber is automatically evacuated.

Note: Since the filament saturation position may change after exchanging the filament, the FILAMENT knob (L1-2) stopper position should be adjusted in order to prevent the filament from overheating which shortens filament life.

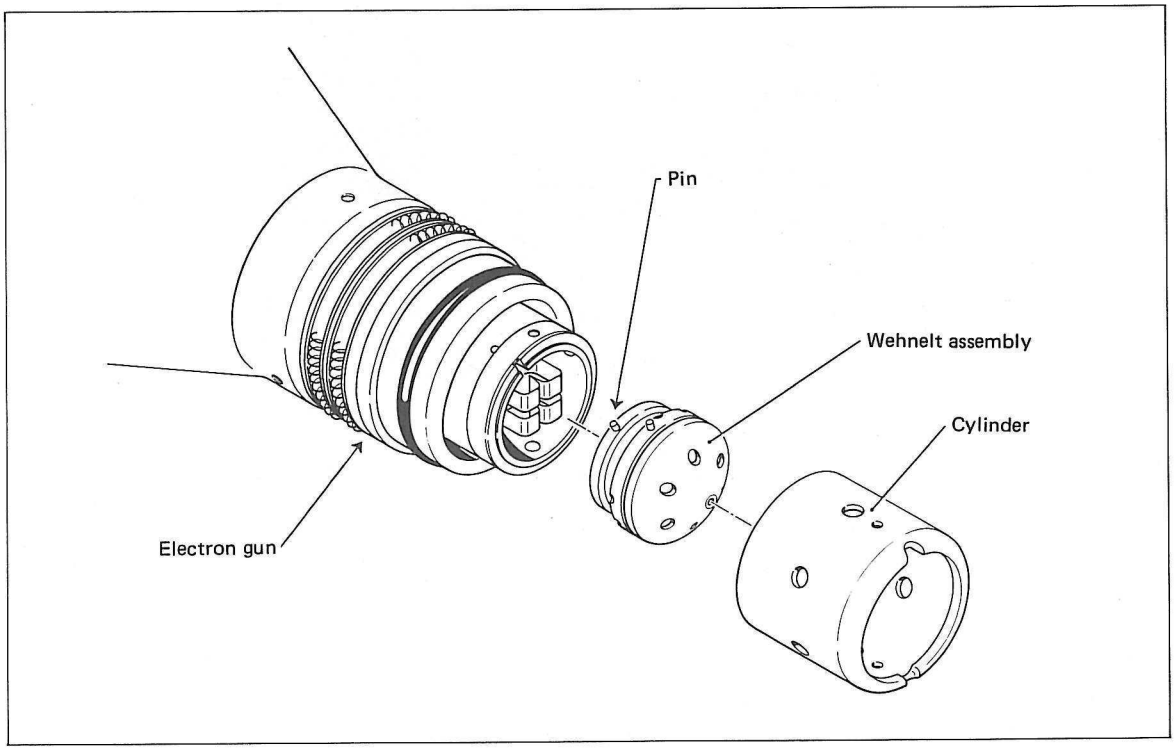


Fig. 6.1-6 Wehnelt mounting

6.2 Small fluorescent screen replacement

Long use of the fluorescent screen deteriorates the phosphor coated on the screen, with the result that the brightness and sharpness of the image are adversely affected. In such case, replace the effete small fluorescent screen with the spare one as provided, and contact your nearest JEOL Service Center to have the old screen re-conditioned. To replace the screen, proceed as follows:

1. Admit air into the viewing chamber.

   1a. Set the FILAMENT knob (L1-2) to OFF.

   1b. Turn the camera chamber door handle clockwise as far as it will go.

2. Fix the two suction disks (Fig. 3.2-1) on the viewing chamber window glass, and carefully remove the glass with both hands (Fig. 6.2-1).

   Place the removed glass in a clean spot with its inner surface facing upwards.

   Cautions: *1. Be careful not to touch or rub against the inner surface of the glass as it has been specially treated with conductive material.*

   2. Be careful not to drop the window glass or bump its corners as it is lead glass which is brittle and easily broken.

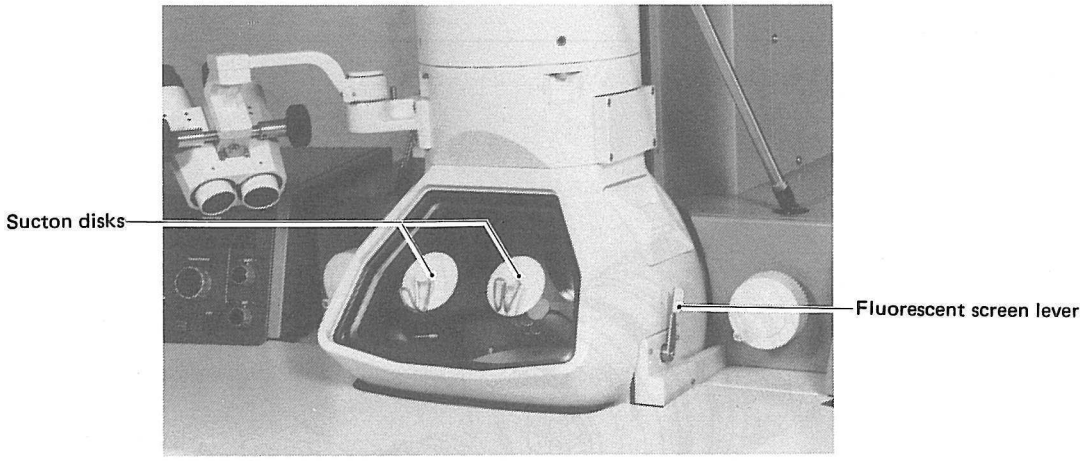


Fig. 6.2-1 Viewing chamber

3. While holding the small fluorescent screen bar with one hand, carefully remove the screen with the other (Fig. 6.2-2).

   Caution: Be careful when handling the screen as its fluorescent surface is easily scratched.

4. Carefully insert the new fluorescent screen with one hand while holding the screen bar with the other.

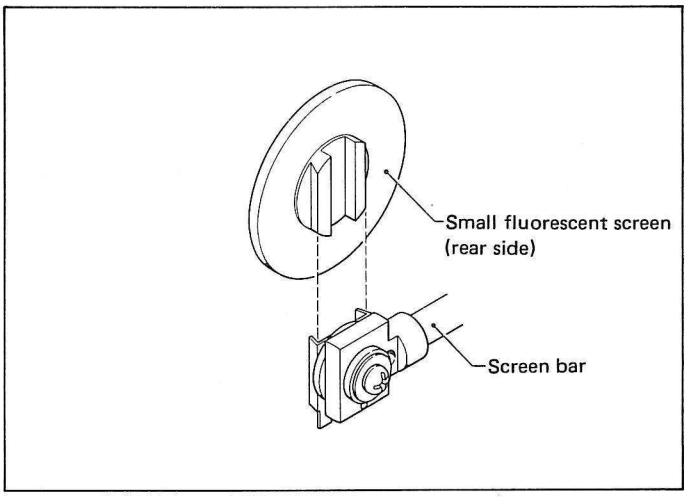


Fig. 6.2-2 Small fluorescent screen replacement

5. Replace the glass after making sure that the glass grounding spring (at A in Fig. 6.2-1) is properly set (Fig. 6.2-3), and the O-ring and its mating surface are free from lint.

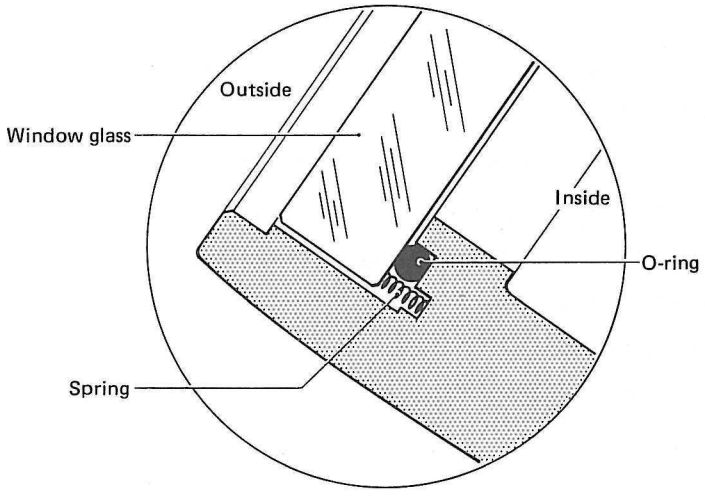


Fig. 6.2-3 Glass grounding spring

6. Close the camera chamber door, and while pressing the door, turn the door handle counterclockwise until it stops. Evacuation of the camera chamber commences. When the evacuation is completed, valve V3 automatically opens.

   Note: Valve action is shown on PAGE-3.

6.3 Freon gas replenishment

6.3.1 Electron gun gas chamber

If the reading of the gas chamber pressure gauge (Fig. 6.3-1) drops below 1.7, replenish the chamber with freon gas as follows:

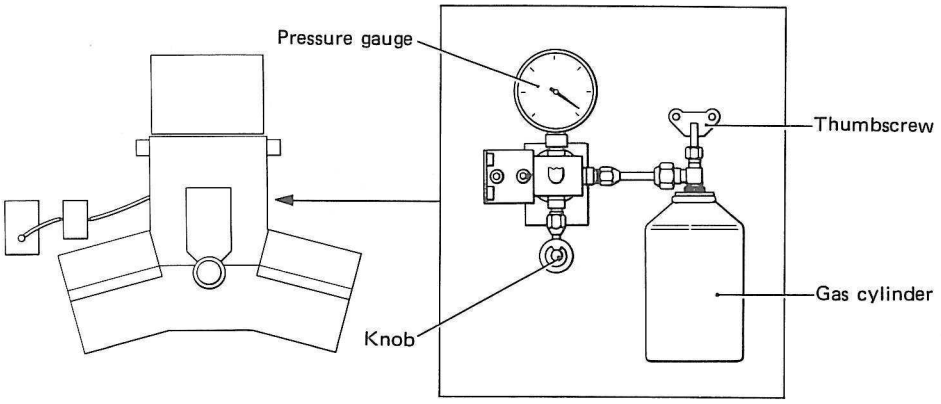


Fig. 6.3-1 Freon gas controller

1. Set the FILAMENT knob (L1-2) to OFF and turn off the accelerating voltage.
2. If a gas cylinder has not been connected to the gas controller for the gas chamber, carry out the following procedure. After connecting a gas cylinder, proceed to Step 5 below.
3. Attach the gas control valve (Fig. 6.3-2) to the freon gas cylinder.
   3a. Move the nut in the arrow's direction (Fig. 6.3-2) by turning it until it stops.
   3b. Turn the thumbscrew fully counterclockwise.
   3c. Screw the gas control valve fully into the gas cylinder and tighten the nut.
   3d. Turn the thumbscrew fully clockwise.

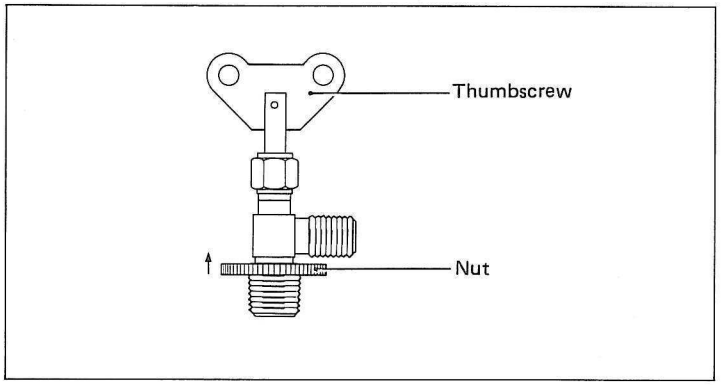


Fig. 6.3-2 Gas control valve

4. Connect a gas cylinder firmly to the pipe with a wrench.
5. While watching the pressure gauge, gradually turn the thumbscrew counterclockwise, and when the gauge reading reaches 1.95, turn it fully clockwise. If the gauge reading is less than 1.75 when the thumbscrew is turned fully counterclockwise, replace the gas cylinder with a new one as follows.
6. Set the knob (Fig. 6.3-1) to C (Fig. 6.3-3).

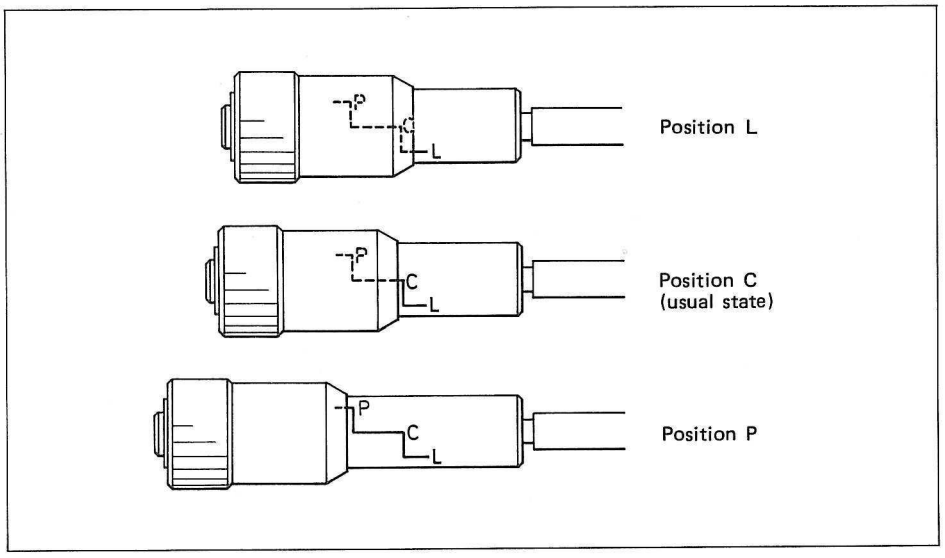


Fig. 6.3-3 Gas control knob

7. Loosen the nut (Fig. 6.3-4) and disconnect the gas inlet tube.
8. Turn the thumbscrew fully counterclockwise.
9. Turn the nut (Fig. 6.3-2) fully counterclockwise.
10. Remove the gas cylinder by turning it counterclockwise and connect a new one.
11. Tighten the nut by turning it clockwise.
12. Set the knob to P (Fig. 6.3-3) and, when the pressure gauge indicates 760 mmHg, set the knob to C.
13. Turn the thumbscrew fully clockwise.
14. Connect the gas inlet tube.
15. While watching the pressure guage, gradually turn the thumbscrew counterclockwise, and when the gauge reading reaches 1.95, turn it fully clockwise.

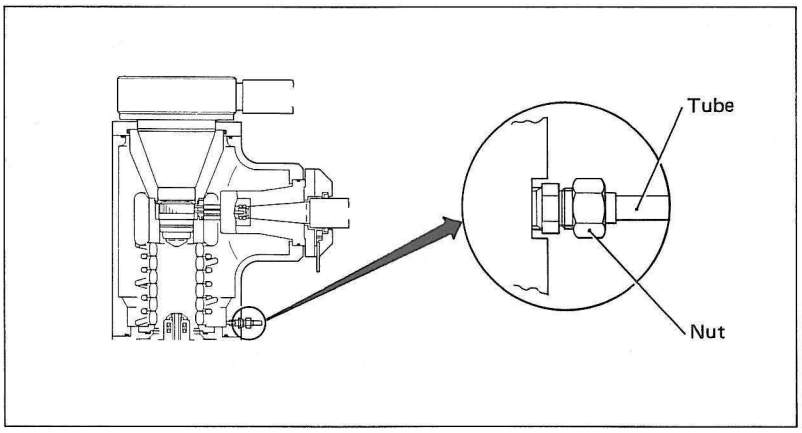


Fig. 6.3-4 Gas inlet tube

6.3.2 HT tank

If the reading of the pressure guage on the HT tank top drops to 0.05, replenish the tank with freon gas as follows:

1. Turn off the accelerating voltage.
2. Connect a gas cylinder to the HT tank as follows:
   2a. Attach the gas control valve to a gas cylinder (see Step 3, Subsect. 6.3.1).
   2b. Remove the cap from the HT tank gas inlet nozzle.
   2c. Connect the gas cylinder to the HT tank (Fig. 6.3-5).
3. While watching the pressure gauge, gradually turn the thumbscrew counterclockwise, and, when the gauge reading reaches 0.1 kg/cm^2, turn it fully clockwise. If the gauge reading does not increase when the thumbscrew is turned counterclockwise, remove the gas cylinder and replace it with a new cylinder as per Step 4 below.

   Note: The allowable gas pressure range is between 0.05 kg/cm^2 and 0.15 kg/cm^2. However, it is necessary to replenish the tank with freon gas so that the pressure gauge indicates 0.1 kg/cm^2, since the gauge reading varies according to the ambient temperature (0.03 kg/cm^2 for 10°C).
4. Turn the thumbscrew fully counterclockwise, then turn the nut fully counterclockwise (Fig. 6.3-2).
5. Remove the gas cylinder by turning it counterclockwise and connect a new one.
6. Tighten the nut by turning it clockwise; then turn the thumbscrew fully clockwise.
7. Replenish the tank with gas (see Setp 3 above).
8. Remove the pipe and adapter (Fig. 6.3-5), and replace the cap nut and gasket.

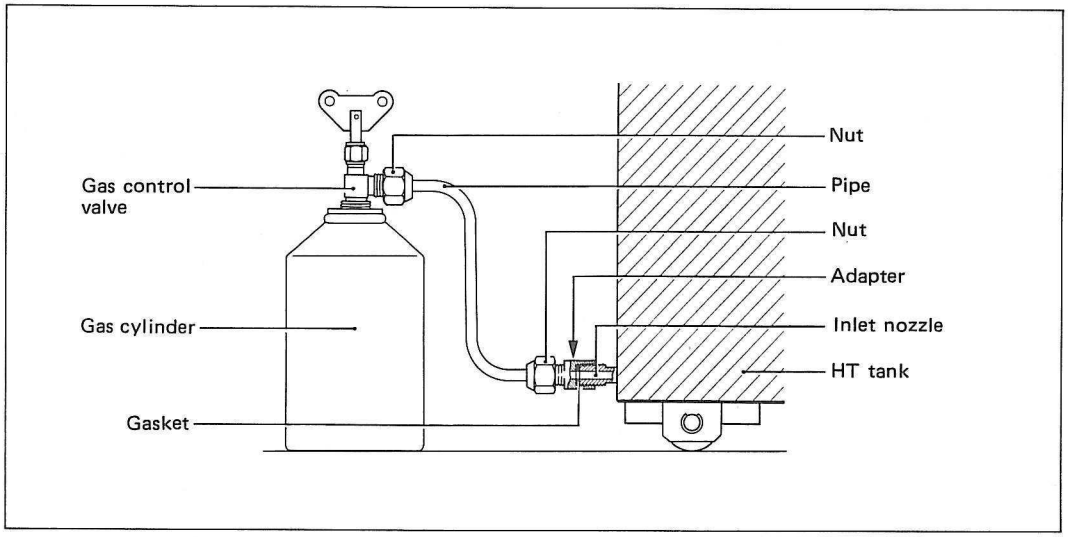


Fig. 6.3-5 Connecting gas cylinder

6.4 Cleaning the column parts

After prolonged operation, the column interior becomes contaminated by electron beam bombardment and instrument performance is adversely affected. Accordingly, in order to ensure observation of excellent images at all times, clean (or replace) the contaminated parts periodically.

6.4.1 Precautions

a. When handling column parts, be sure to wear thin work gloves in order to prevent contamination by perspiration, etc., which could cause charging due to corrosion of the parts.

b. Avoid using metal tools, because even a slight scratch on a component part may adversely affect column vacuum and cause the electron beam to be improperly deflected.

c. Exerting force when inserting or removing parts may distort or damage them. Be specially careful when inserting or removing the pole pieces.

d. Prolonged exposure of the column parts to the atmosphere will cause corrosion of their surfaces. Disassembly, cleaning, and reassembly must be completed quickly.

e. When removing or fastening screws, nuts, etc., use the proper tools for them in order not to damage screw heads and threads.

f. Keep the O-rings and their mating surfaces free from scratches, dust, lint, etc. Even a slight scratch or fine dust will adversely affect the column vacuum. Be sure to use the specified types of vacuum grease as per Sect. 6.4.6.

g. When using organic solvent, select an adequately ventilated place without fire hazard, and do not allow prolonged contact with the skin.

6.4.2 Cleaning materials, tools, etc.

a. Cleaning liquid (organic solvent)

To remove grease, etc. and traces of metal polish. The cleaning liquid should be volatile, containing little impurity, preferably non-inflammable, and should have a high solution-forming rating (high cleaning power) and a high safety factor.

b. Fine grain metal polish

To remove encrustation and other extraneous matter having high adhesive properties. The polish should be easy to remove with organic solvent.

c. Gauze or rayon paper (crepe or gauze type)

To apply metal polish or cleaning solvent. The gauze or rayon paper should be of high quality and not release impurities when moistened with organic solvent.

d. Absorbent cotton

To clean scratched parts and important parts. By wrapping the cotton around a thin stick, it can also be used for cleaning difficult-to-get-at corners and recesses. The cotton should be of high quality.

e. Cotton swabs or toothpicks

To clean narrow places. Any commercially available (but untreated) product is suitable.

f. Sticks (about 5 mm dia.) or chopsticks

With absorbent cotton wrapped around them, they are used for cleaning the inside of cylindrical parts. Any commercially available (but untreated) product which is straight and round is suitable.

g. Beakers

To clean small parts in them. Should be made of stainless steel or aluminum, or enamel-coated. (Glass is not recommended as it breaks easily.

h. Thin work gloves

To be worn when handling the internal parts of the column to prevent contamination and corrosion due to perspiration. Any commercially available cotton, nylon, or polyethylene gloves are suitable.

6.4.3 Cleaning methods

Cleaning method A (using cleaning liquid)

Application: Cleaning of lightly contaminated parts, not critical parts, and parts where metal polish is unsuitable (likely to affect microscope performance)

For flat surfaces, moisten a piece of gauze, rayon paper, or absorbent cotton with cleaning liquid (organic solvent), and rub the surface in question until it becomes clean. In the case of holes or the interior of cylindrical parts, use cotton swabs, or toothpicks or the like wrapped in absorbent cotton.

To remove oil, etc. from intricate or threaded parts, immerse the parts in a beaker of solvent. Replace the solvent when it becomes dirty. An ultrasonic cleaner is highly effective for cleaning extremely complicated parts. Immediately after removing the parts from the beaker of solvent, remove any traces of liquid with the hand blower.

Cleaning method B (using metal polish and then removing the polish with cleaning liquid)

Application: Cleaning of heavily contaminated parts (where metal polish usable)

For flat surfaces, apply a small amount of metal polish to a piece of gauze, rayon paper, or absorbent cotton, and rub the surface in question until it becomes clean. In the case of holes or the interior of cylindrical parts, use cotton swabs, or toothpicks or the like wrapped in absorbent cotton. Refrain from applying polish to intricate or threaded parts.

Avoid applying excessive force when rubbing the contaminated surfaces. To clean apertures, we recom-

mend the use of a cotton swab of the same size as the hole. Clean the holes by rotating the swab evenly. If this recommendation is unheeded, there is a possibility of pushing the hole out of shape.

Remove any traces of polish with cleaning liquid by repeating method A cleaning several times. If some polish remains, it will in itself become a contaminant, completely defeating the object of the task in hand. Finally, keep the cleaned parts covered until ready for reassembly.

Cleaning method C (heating in a vacuum evaporator)

Application: Cleaning of parts having a high melting point (tantalum or molybdenum foil, etc.)

By using the JEE Vacuum Evaporator, the apertures can be cleaned as follows (refer to the JEE Vacuum Evaporator Instructions):

1. Remove the bell-jar from the vacuum evaporator.
2. Mount the boat on the vacuum evaporator electrodes, using washers (Fig. 3.2-1) as shown in Fig. 6.4-1.

JEE vacuum evaporator

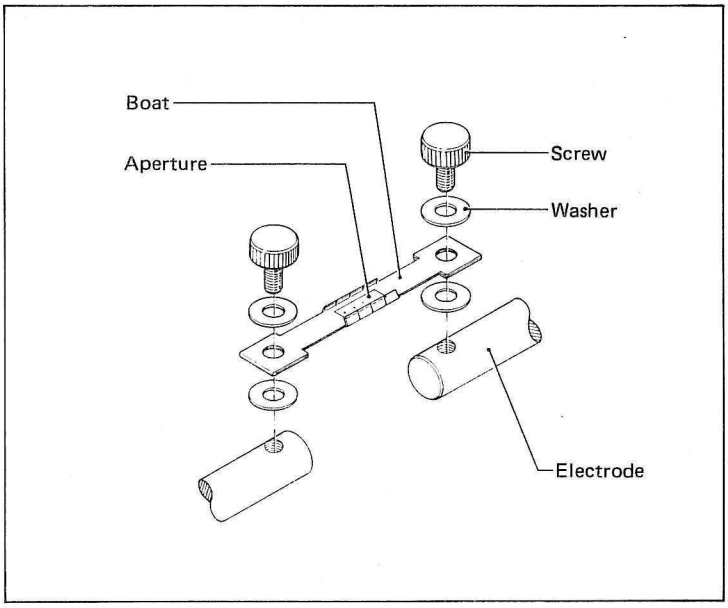


Fig. 6.4-1 Aperture cleaning

3. Replace the bell-jar, and pump the jar to better than 1×10^{-4} Torr (1.3×10^{-2} Pa).
4. Heat the boat by passing a current of 30 A for about one minute.
5. Allow three minutes after heating before breaking the bell-jar vacuum.
6. Break the bell-jar vacuum and remove the bell-jar.

7. Place an aperture (only one aperture at a time) in the boat.

   Caution: Use tweezers to handle the aperture, and be sure not to scratch or deform it.

8. Repeat Steps 3 to 6.
9. Remove the aperture.

6.4.4 Parts requiring cleaning

Section	Component part	Cleaning method	Cleaning frequency
Electron gun	Wehnelt	B	When changing the filament
	Cylinder	B	
Condenser lens aperture assembly	Aperture disks	C	Every 6 months
	Aperture holder	A	
Objective lens aperture assembly	Aperture foil	C	
	Aperture holder	A	
Field limiting aperture assembly	Aperture foil	C	
	Aperture holder	A	

Note: See Sect. 6.4.3 for the cleaning methods.

6.4.5 Removing and cleaning parts

6.4.5a Electron gun

1. Remove the Wehnelt assembly as per Sect. 6.1.
2. Clean the cylinder, filament holder and Wehnelt cap using method B.

   Caution: Do not touch the insulator and anode chamber inner wall.
3. Replace the Wehnelt assembly.
4. Evacuate the anode chamber in accordance with Sect. 6.1.

6.4.5b Aperture assemblies

1. Admit air into the column (see Sect. 6.4.7).
2. Turn the condenser lens, objective lens, and field limiting aperture lever to the left side.
3. Remove the fixing screws of the aperture assemblies, and slowly draw out the assemblies (Fig. 6.4-2).

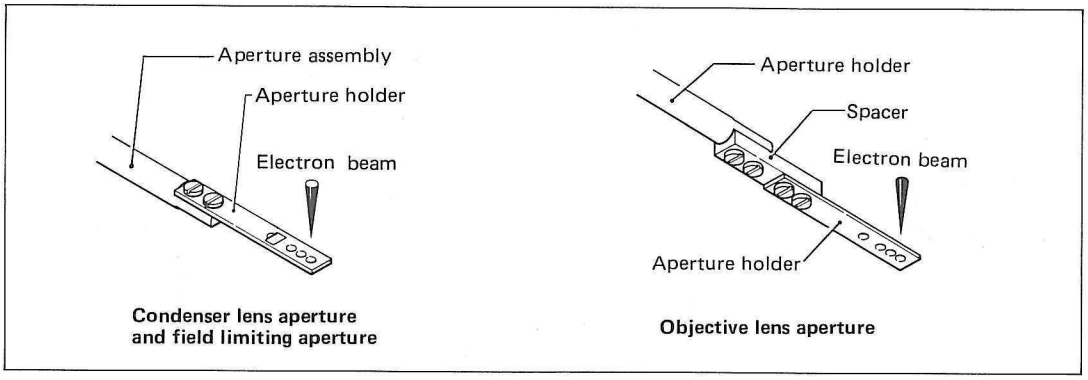
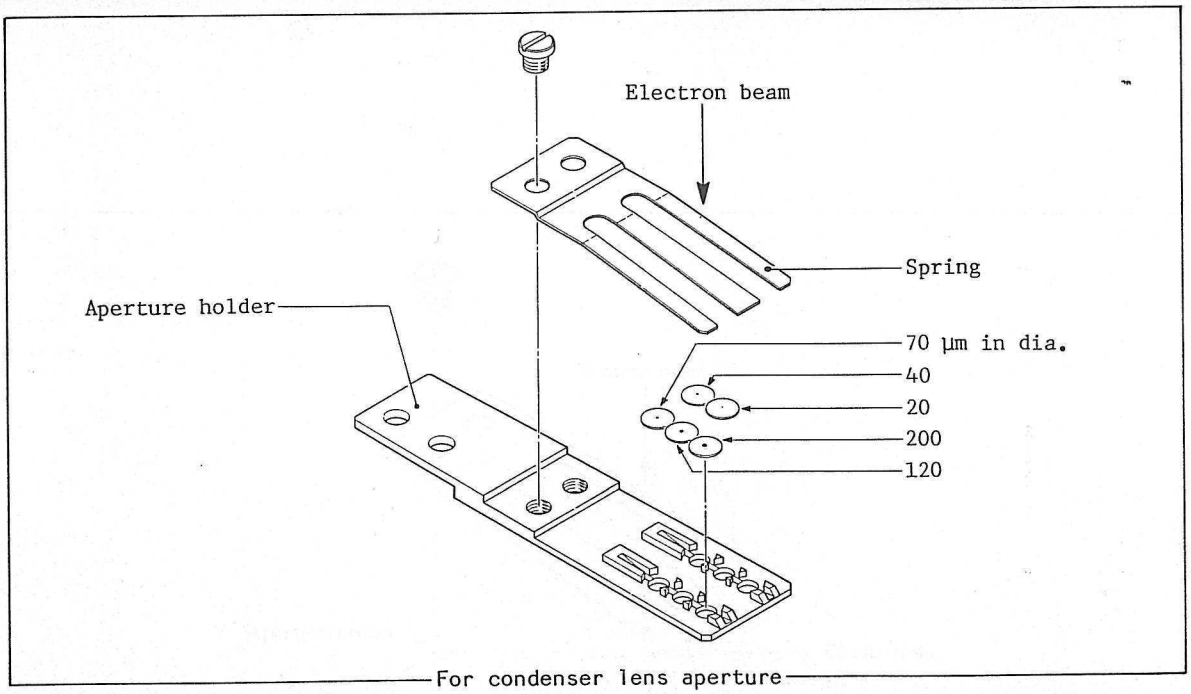


Fig. 6.4-2 Aperture holder mounting

4. Remove the aperture foil or disks from each aperture holder with tweezers (Fig. 6.4-3).
5. Clean the aperture foil or disks using cleaning method C, and the aperture holders using method A.
6. Reassemble and replace the aperture assemblies.
7. Evacuate the column (see Sect. 6.4.7).



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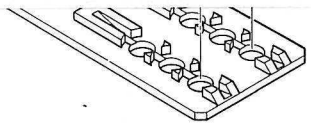
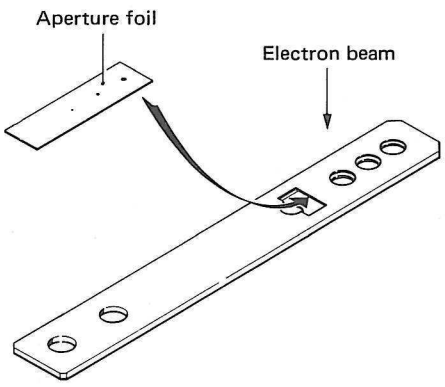


7. The figure "For condenser lens aperture" in Fig. 6.4-3 should be replaced with the following.



For objective lens and field limiting apertures

Fig. 6.4-3 Aperture holder assembling

6.4.6 Use of vacuum grease

Two types of vacuum grease, Fomblin and Apiezon, are provided. Be sure to use Fomblin as provided on the O-rings within the enclosed section in Fig. 6.4-4, and on attachments to be installed in the same section. Use Apiezon as provided on other O-rings.

As a rule, apply grease only to movable parts and difficult-to-remove/replace parts. The amount of grease applied must be minimum.

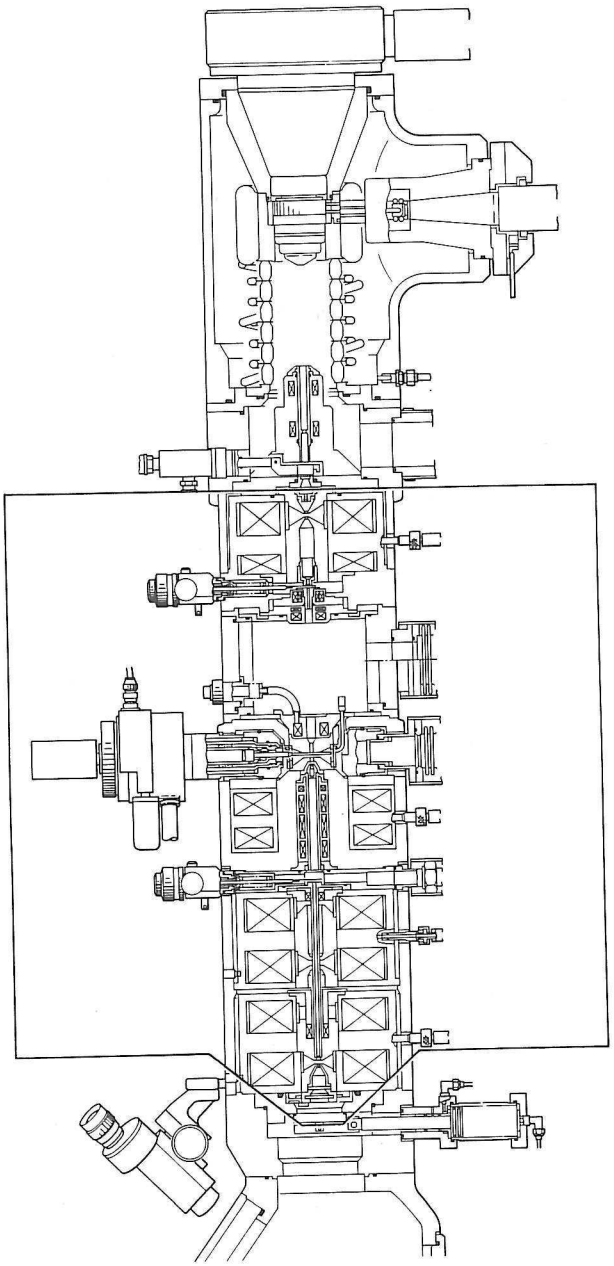


Fig. 6.4-4 Use of vacuum grease

6.4.7 Breaking the column vacuum and re-evacuation

6.4.7a Admitting air into the column

1. Set the FILAMENT knob (L1-2) to OFF, and release the HT button (L1-6).
2. Remove the specimen holder, and remove all the apertures from the electron beam path.
3. If the anticontamination device (optional) has been mounted, raise the anticontamination device cooling trap temperature to room temperature (see EM-ACD Instruction manual).

   Caution: If air is admitted into the column with the cooling trap (in the specimen chamber) in the cooled state, moisture will condense into water droplets and ice will form on the trap and adjacent parts, causing rust.
4. Confirm that the PI2 and PI3 values (displayed on PAGE-3) are both 150μA or less. If both values or either one of them is larger than 150μA, evacuate the anode and camera chambers until both values decrease to 150μA or less.
5. Depress the COL AIR button (L2-5). Air is now admitted into the anode chamber and column (except the viewing chamber).
6. If air is to be admitted also into the viewing chamber and camera chamber, turn the camera chamber door handle clockwise as far as it will go.

6.4.7b Re-evacuating the column

1. Confirm that all the parts removed have been replaced.
2. Make sure the electron gun has not been lifted and camera chamber door is closed.
3. Switch off the COL AIR button (L2-5).

6.5 Baking out the column

6.5.1 Complete bake-out

Specimen contamination can be considerably reduced by heating the column and freeing adsorbed gas molecules from the column interior walls. Bake out of the column interior is recommended if it has been exposed to air for a long time.

1. Display the maximum accelerating voltage on PAGE-1 using the ACCEL VOLTAGE switch (L1-5).
2. Turn the FILAMENT knob (L1-2) to OFF and release the HT switch (L1-6).
3. After confirming that the LENS POWER SUPPLY switch (L2-2) is set at ON, depress the BAKE OUT switch (L2-7).

Caution: Do not tamper with the switches and controls on the control panels until the BAKE OUT switch (L2-7) is released. If inadvertently tampered with, release the BAKE OUT switch (L2-7) and redepress it.

4. Close the lens cooling water valve (Fig. 6.5-1).

VYPNOUT ALIGNMENT ČOČEK V PRAVÉ NOŽE MIKROSKOPU

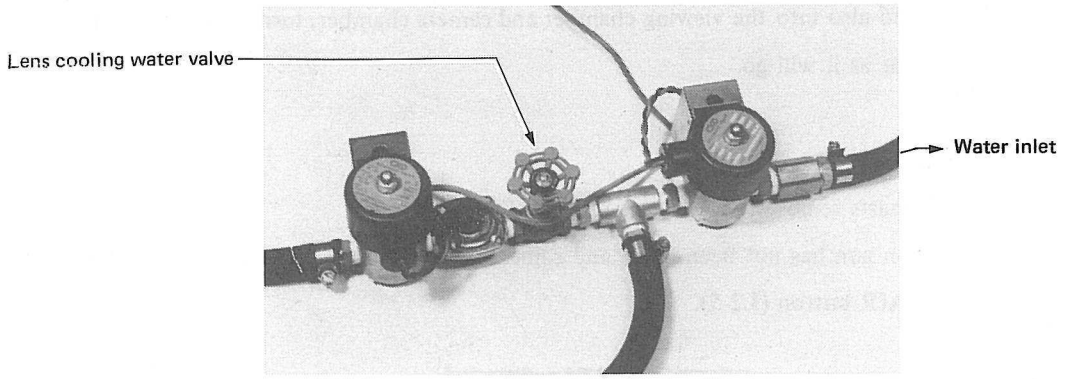


Fig. 6.5-1 Lens cooling water valve

5. Wait about 10 hours.
6. Turn off the LENS POWER SUPPLY and BAKE OUT switches (L2-2, L2-7).
7. Wait about 3 hours more.
8. Fully open the lens cooling water valve, then turn on the LENS POWER SUPPLY switch (L2-2).

6.5.2 Simple bake-out

If the microscope is turned in the unatteneded evacuation mode before returning the EM-ACD anti-contamination device (optional attachment) temperature to room temperature, a large amount of gases absorbed on the device's cooling trap will be released during column evacuation. Such gas releases, when an SIP (sputter ion pump) is incorporated, cause valve V12 to open and close repeatedly, which adversely affects the evacuation system. In order to prevent this, carry out the unattended evacuation as follows:

1. Turn the FILAMENT knob (L1-2) to OFF and release the HT switch (L1-6).
2. After confirming that the LENS POWER SUPPLY switch (L2-2) is set at ON, depress the BAKE OUT switch (L2-7).
3. Leave the microscope with the lens cooling water running.
4. Turn off the BAKE OUT switch before using the microscope.

6.6 Troubleshooting

6.6.1 Concerning start-up

6.6.1a When impossible to start up

Cause	Remedy
a. Turned off circuit breaker *Note: The breaker is in the power supply console.*	Switch off the main power and set the breaker to ON. Then start up the instrument after switching on the main power.
b. Broken fuse F4 (see Subject. 6.6.5).	Replace.

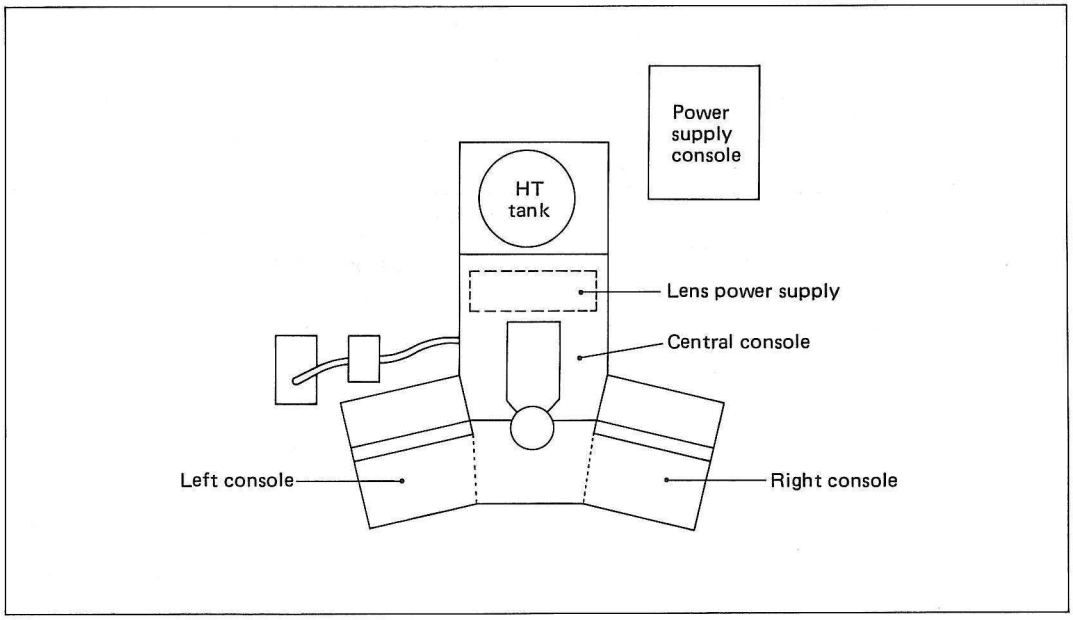


Fig. 6.6-1

6.6.1b When the instrument stops automatically some time after start-up

Cause	Remedy
a. Insufficient water pressure (in this case the instrument stops in 2 or 3 seconds)	Increase the pressure.
b. The radiator fan in the power supply console is broken (in this case the instrument stops when the radiator temperature reaches 90°).	Contact your nearest JEOL representative.
c. Compressed air pressure less than 3.2 kg/cm^2.	Contact your nearest JEOL representative.

6.6.1c When the READY lamp does not light up

Cause	Remedy
a. Disengaged HV cable electron gun side	Switch off the HV and connect the cable to the electron gun.
b. Closed anode chamber airlock valve V2	Evacuate the anode chamber and wait until V2 opens.

6.6.2 Concerning the electron beam

6.6.2a When no electron beam appears on the screen

Cause	Remedy
a. No electron beam is generated.	See Subsect. 6.6.2b.
b. The specimen number indicator is pointing between 1 and 2.	Set the indicator to 1 or 2.

6.6.2b When no electron beam is generated, i.e. the BEAM CURRENT meter reading increases less than 3 μA when the FILAMENT knob on control panel L2 is turned clockwise

Cause	Remedy
a. Unlit READY lamp	See Subsect. 6.6.1c.
b. Closed viewing chamber airlock valve V3	Evacuate the camera chamber and wait until V3 opens.
c. Insufficient BIAS MODE value (control panel L1)	Set to 70~80.
d. Insufficient distance between the Wehnelt cap and filament tip	See Subsect. 6.1.
e. Burnt out gun filament	Replace (see Subsect. 6.1).

6.6.3 Concerning the specimen

6.6.3a When a focussed image cannot be obtained

Cause	Remedy
a. Improper Z control knob setting	Carry out the tilt axis alignment (see Subsect. 5.8).

6.6.3b When the specimen cannot be tilted

Cause	Remedy
a. Motor and goniometer are disengaged.	Make the lamp light up by pulling the motor towards you.
b. The X-TILT knob on the GONIO CONTROL (control panel L1) set to 0	Set to 4~6.

6.6.3c When the end of the specimen image cannot be shifted to the screen center

Cause	Remedy
a. Improper specimen selector setting	Set the selector so that the entire field of view can be seen in the screen center (see Step 7, Subsect, 5.2.6).

6.6.4 Voltage checking

6.6.4a Power supply console (Fig. 6.6-1)

The various voltages, as listed below, can be measured by connecting a volt meter to the checking terminals located behind the front door.

Voltage	Related fuse number
+15 V, CAMERA	F33
−15 V, CAMERA	F34
+15 V, CARD	F29
−15 V, CARD	F30
+5 V, CARD	F19, 20
+24 V, VALVE	F3

6.6.4b Central console (Fig. 6.6-1)

The various voltages, as listed below, can be measured by connecting a volt meter to the checking terminals located behind the left panel.

Voltage	Related fuse number
+100V, lenses	F17
+5 V, shutter	F31
−15 V, lenses	F27
+5 V, lenses	F26
+15 V, lenses	F25
+15 V, beam deflectors	F28
−15 V, beam deflectors	F16
+5 V, beam deflectors	F15

6.6.4c Lens reference voltages

The reference voltages of all the lenses are shown on the CRT (PAGE-4). The standard voltages are listed below.

Note: These voltages are for 200 kV when the AHP is used. Multiply the listed voltages by 0.88, 0.75, 0.68, and 0.60 for 160, 120, 100 and 80 kV respectively.

Reference voltages for the lens currents

Lens	Measuring condition	Voltage
CL1	At 5,000X, SPOT SIZE knob to 1	4.15 ~ 4.20
CL2	At 5,000X, CL2 current maximized with the BRIGHTNESS knobs	8.00 ~ 8.20
CM		0.00
OL	At 5,000X, OL current maximized with the OBJ FOCUS knobs	8.00 ~ 8.40
OM	At 3,000X	5.00 ~ 5.10
PL	At 5,000X	7.40 ~ 7.50
IL3	At 5,000X	5.80 ~ 5.95
IL2	At 1,000,000X	7.58 ~ 7.65
IL1	At 1,000,000X	7.90 ~ 7.95

6.6.5 Fuses and corresponding circuits

6.6.5a Inside the power supply console

F. No.	Rating	Corresponding circuit, pump, etc.
1	2 (A)	Card rack cooling fan, Penning gauge
2	5	AC 100 V outlets
3	1	For attachments use
4	1	Start-up circuit
5	10	Transformer 3 (F19 ~ 34 are related)
6	5	Oil rotary pump
8	5	Oil diffusion pumps (supplied to order)
9	5	
10	20	Transformer 2 (F11 ~ 18 are related)
11	5	HT UNIT, +75 V
12	1	HT UNIT, +5 V
13	1	HT UNIT, +15 V
14	1	HT UNIT, −15 V
15	10	LENS UNIT, +15 V, deflectors
16	10	LENS UNIT, −15 V, deflectors
17	15	LENS UNIT, +90 V, lenses
18	15	
19	15	CARD UNIT, +5V
20	15	
21	15	Solenoid valves, +24 V
22	15	

F. No.	Rating	Corresponding circuit, pump, etc.
23	0.5	Solenoid valves, −5 V
24	5	Solenoid valves, +5 V
25	2	LENS UNIT, +15 V, lenses
26	2	LENS UNIT, −15 V, lenses
27	3	LENS UNIT, +5V, lenses
28	3	LENS UNIT, +5 V, deflectors
29	10	CARD UNIT, +15 V
30	10	CARD UNIT, −15 V
31	3	LENS UNIT, +5 V, shutter
32	2	PRINTER UNIT (supplied to order), −30 V
33	3	CAMERA UNIT, +15 V
34	3	CAMERA UNIT, −15 V
35	2	ROOM LIGHT

6.6.5b Camera chamber

A fuse for the motor is located behind the left door of the chamber.

6.6.6 Self-diagnostic function

When starting up and when depressing the [C][H][E][C][K][RETURN] keys on the keyboard, whether the bus lines of each interface PC board are normal is displayed on the CRT. If all the bus lines are normal, "NO PB ERROR" is displayed; otherwise a name of the board is displayed on the CRT. The following PC boards are diagnosed:

1. DEF PB
2. LENS PB
3. LENS PB, DEF LENS ITF PB
4. DEF PB, DEF LENS ITF PB
5. CAMERA ITF PB
6. HT VAC ITF PB
7. AD CONV PB
8. LEFT PANEL ITF PB
9. RIGHT PANEL ITF PB
10. FC ITF PB (supplied to order)
11. IRT KEY BOARD ITF PB
12. PRINTER ITF PB (supplied to order)

Notes: 1. No. 1 is located on the front panel of the right console, No. 2 is located on the lens power supply in the central console, and No. 3 ~ 12 are inserted in the card rack located behind the right console rear side (Fig. 6.6-1). The lens power supply can be pulled out of the console left side.

2. No. 3 means the lens side circuit of the DEF LENS ITF PB is not normal, and No. 4 means the deflector side circuit of the PB is not normal.

6.7 Restarting the CPU

When the CPU function has stopped during operation, restart the CPU as follows.

1. Display an * mark on the CRT upper left corner with the A (KB-2) while depressing the CTRL (KB-2).
2. Depress [R][E][S][E][T][RETURN]. The contents of PAGEs change as follows.

   PAGE-1: Almost all the values become zero, the TEXT information is erased, and SHP20 is displayed as the pole piece name.

   PAGE-2: The stored specimen positions are erased.

   PAGE-3: Displays the DVS diagram.

   PAGE-7: The COMMENT information is erased.

   PAGE-8: Erased.

   Lens currents: All the lens currents are turned off.

3. Enter the information as follows.

   - Depress first [E][X][T][E][R][N][A][L][=], then [O][F][F][RETURN] (When EM-AMS has not been attached) or [O][N][RETURN] (when EM-AMS has been attached).
   - [C][L][3][=][O][N][RETURN]
   - [V][A][C][=][a][a][a][RETURN]

     aaa: Name of evacuation system. DVS (for SIP-DP), DCS (for DP-DP) or TMP (for SIP-TMP).
   - [P][P][=][a][a][a][,][b][RETURN]

     aaa: OL pole piece name (SAP, AHP, SHP, etc.)

     b: CL pole piece name (D or S)
   - [8][P][=][1][,][2][,][3][,][4][,][6][RETURN]
   - Depress first [S][C][R][E][E][N][=], then [O][F][F][RETURN] (when EM-MMD has not been attached) or [O][N][RETURN] (when EM-MMD has been attached).

4. Erase the * mark on the CRT upper left corner with the A (KB-2) while depressing the CTRL (KB-2).
5. Carry out the settings of the HT (minimum amount of accelerating voltage change), SE (exposure index) and F NO (film number and number of unused films), and writing of the TEXT (see Subsect. 5.2.11).
6. Turn on the LENS (L2-9) one by one.
7. Carry out the setting of the OUF (optimum under focus, see Subsect. 5.2.11).

7. PRINCIPLE

7. PRINCIPLE

7.1 General principles

7.1.1 Comparison between electron microscope and optical microscope

Fundamentally and functionally, electron microscopes (EM) and optical microscopes (OM) are idnetical. That is, both types of microscope magnify minute objects normally invisible to the naked eye. The basic difference between the two, however, is that an electron microscope uses an electron beam as a specimen illuminating medium whereas an optical microscope uses a light beam (including ultraviolet rays) for this purpose. The main differences between the EM and OM are shown in the following table.

	Electron microscope	Optical microscope
Illuminating beam	Electron beam	Light beam
Wavelength	0.0086 nm (20kV) ~ 0.0025 nm (200kV)	750 nm (visible) ~ 200 nm (ultraviolet)
Medium	Vacuum	Atmosphere
Lens	Electron lens (magnetic or electrostatic)	Optical lens (glass)
Aperture angle	~ 35′ ~	~ 70°
Resolving power	Point to point: 0.35 nm, lattice: 0.14 nm	Visible: 200 nm, ultraviolet: 100 nm
Magnification	100X ~ 1,000,000X (continuously variable)	10X ~ 2,000X (lens exchange)
Focusing	Electrically	Mechanically
Contrast	Scattering absorption, diffraction, phase	Absorption, reflection

Since the illuminating beam of an electron microscope is an electron beam and the medium is vacuous, there are certain limitations. However, by effectively using a wealth of attachments, many advantages can be realized. This is especially true when the microcope combines scanning image microscopy, electron diffraction and X-ray analysis. Basically, component terminology of an electron microscope is similar to that of an optical microscopes (shown in Fig. 7.1-1).

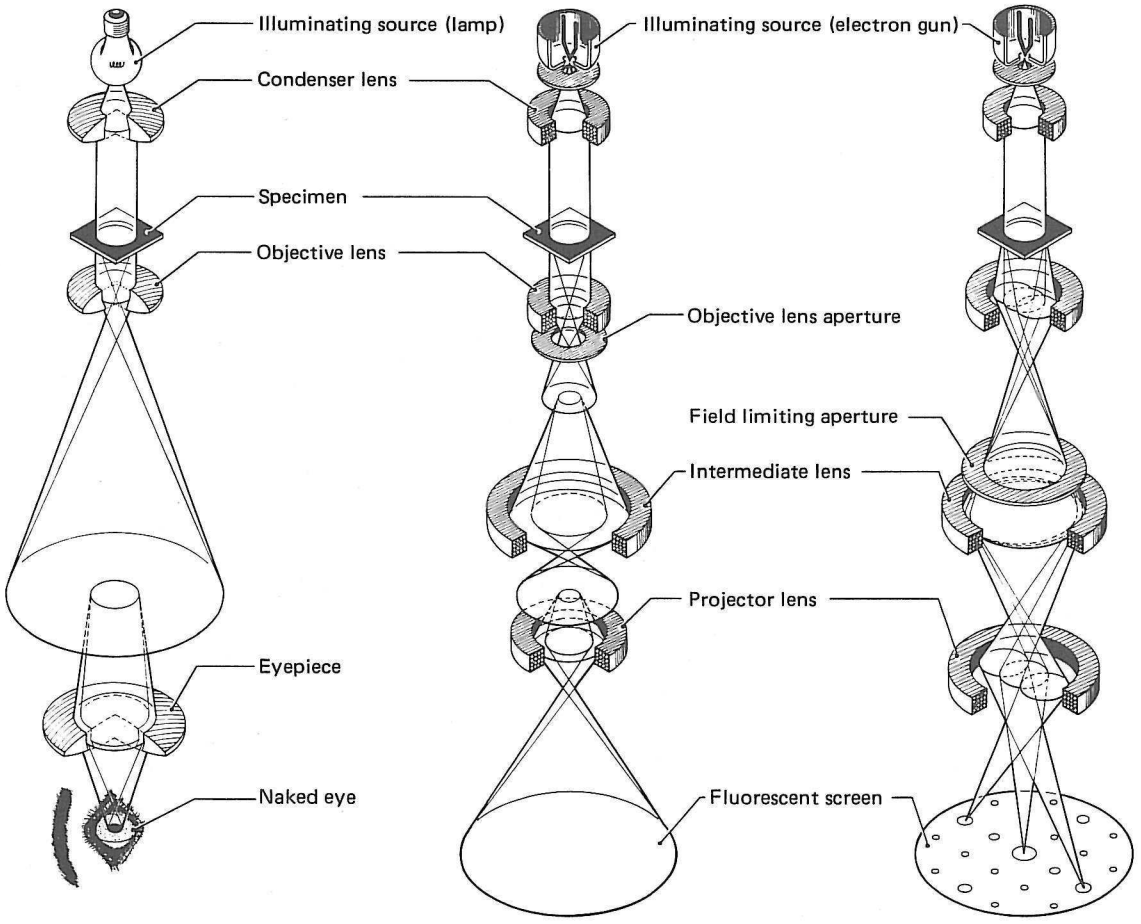


Fig. 7.1-1 Comparison of image formation

7.1.2 Resolving power and resolution

Image quality is usually shown by "resolving power" which is defined as the shortest distance between two points (or two lines) which can be recognized as two different images. However, this term has two different meanings: the resolving power of the instrument and the resolution of the micrograph. It is important that this difference be thoroughly understood.

In the case of the optical microscope, the resolving power, d, is determined by diffraction aberration as follows:

Spherical aberration and chromatic aberration can be removed almost completely;

$$d = \frac{0.61\lambda}{\mu \sin\alpha} = \frac{0.61\lambda}{NA} \quad \cdots\cdots \quad (1)$$

where λ: Wavelength of light　　α: Aperture angle

μ: Refractive index of the object space　　NA: Numerical aperture

On the other hand, electron microscopes are influenced by spherical aberration, which cannot be effectively corrected at present. Therefore, the electron beam near the axis must be utilized and the resolving power of the electron microscope determined by a combination of spherical aberration and diffraction aberration as illustrated in Fig. 7.1-2. O. Scherzer has calculated the limit of resolving power d_{min} and its objective lens aperture angle α_{opt}:

$$d_{min} = 0.43\sqrt[4]{\lambda^3 C_s} \quad \cdots\cdots \quad (2)$$

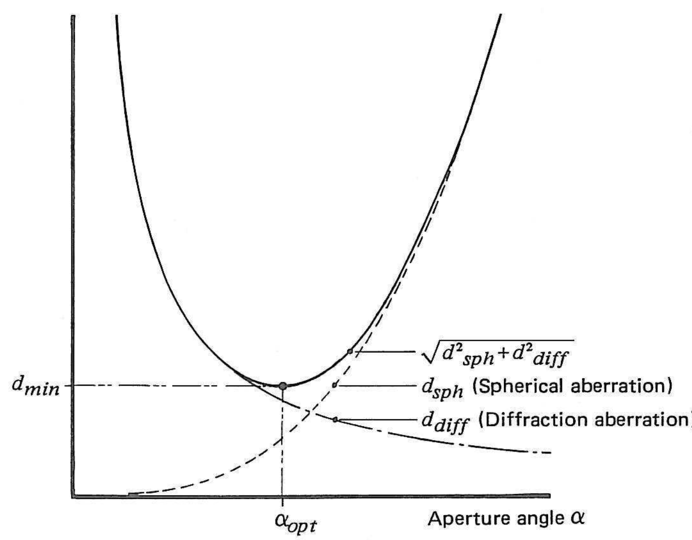


Fig. 7.1-2 Limit of resolving power

$$\alpha_{opt} = 1.41\sqrt[4]{\lambda / C_s} \quad \cdots\cdots (3)$$

where λ: Wavelength of the electrons
C_s: Spherical aberration coefficient of the objective lens

This equation is predicated on the assumption that only spherical aberration and diffraction aberration exist. However, the influence of factors such as chromatic aberration cannot be disregarded in electron microscopy. As mentioned earlier, the removal of aberrations from electron microscopes is much more difficult than in the case of optical microscopes, but with the former a high resolving power can be obtained since the wavelength of electrons is very short, i.e., approximately 1/100,000 of the wavelength of light rays. The wavelength of the electrons λ is usually determined by the accelerating voltage V. And, since the accelerating voltage of an electron microscope is on the order of several tens of kilovolts or higher, corrections based upon the effect of relativity must be taken into consideration in order to calculate the wavelength of the electrons, the equation for which is given as follows:

$$\lambda = \frac{1.2261}{\sqrt{V} \cdot \sqrt{1 + 9.7880 \times 10^{-7} \cdot V}} [\text{nm}] \quad \cdots\cdots (4)$$

Compared with the resolving power of a microscope, the resolution of a micrograph is inferior because of specimen, microscopic and photographic conditions. Accordingly, in order to obtain the best resolution, special attention should be given to specimen preparation, microscopy operation, photographing, the maintenance of the microscope (routine inspection and cleaning), and photographic processing.

To determine the resolving power d visually, a suitable magnification is required. The minimum effective magnification M is determined by the resolving power of the eye d_1, (approx. 0.1 mm) thus,

$$M = \frac{d_1}{d} \quad \cdots\cdots (5)$$

Accordingly, if we assume that the resolving power of an electron microscope and that of an optical microscope are 0.2 nm and 200 nm, respectively, then the effective magnifications for these microscopes will need to be 500,000X or more and 500X or more, respectively.

To ascertain the resolving power, the image to be observed is photographed at a magnification slightly lower than the calculated one and the photographs then enlarged. And since photographs obtained with an electron microscope have a resolution d_2 (approx. 20 μm under good conditions), the required minimum photographic enlargement magnification M_1 is 5X, which is calculated as follows:

$$M_1 = \frac{d_1}{d_2} \quad \cdots\cdots (6)$$

However, an enlargement of more than 5X is even more helpful, since this would allow for a lower d_1.

7.1.3 Principle of the electron lens

Since electron microscopes use an electron beam as an illuminating medium, it follows that electron lenses are used to irradiate the specimen and to form the image to be observed. Electron lenses are usually classified into magnetic and electrostatic lenses (employing axially symmetric magnetic and electric fields, respectively) and special purpose electron lenses such as quadrupole lenses. However, since ordinary electron microscopes normally employ magnetic lenses, the following description concerns itself with that type only.

If, when an electron passes through a magnetic field, the direction of the electron is identical to that of the magnetic field, the electron is not subjected to any external force. If, on the other hand, the direction of the electron is perpendicular to that of the magnetic field, the electron is subjected to a force such that the electron travels on a plane perpendicular to the plane which includes the direction of the electron and that of the lines of magnetic force. Moreover, if the intensity of the magnetic field is uniform, the orbit of the electron on the plane will form a circle. In this case, the radius r of the circle can be calculated as follows: Since the force on the electron moving with a velocity v is evB and the centripetal force is $\frac{mv^2}{r}$ (Fig. 7.1-3).

$$r = \frac{mv}{eB} = \frac{v}{\eta B} \quad \cdots\cdots \quad (7)$$

where
- m: Mass of electrons
- v: Velocity of electrons
- e: Electric charge of electrons
- B: Magnetic flux density
- η: Specific charge of electron e/m

As this equation illustrates, if the magnetic flux density is uniform, the radius of the circular orbit formed by the electron, which crosses the magnetic field at right angles, is proportional to the velocity of the electron.

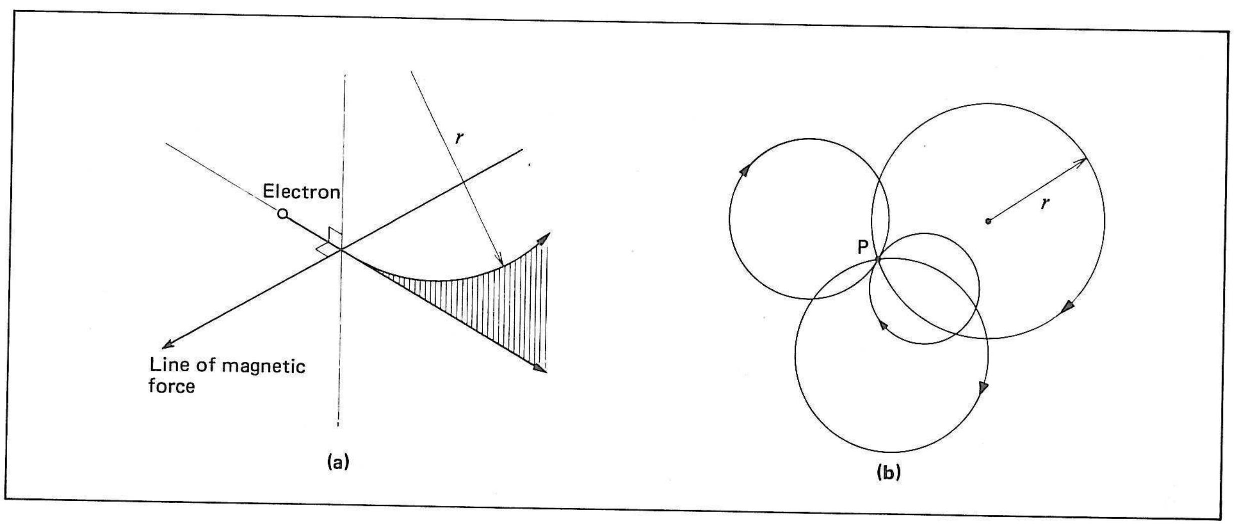


Fig. 7.1-3 Electron trajectories

When several electrons are simultaneously emitted at different velocities and directions from point P on a plane perpendicular to the uniform magnetic field, each electron forms a circular orbit with a radius proportional to its velocity and returns to point P as illustrated in Fig. 7.1-3. The time τ required for one revolution is given as follows:

$$\tau = \frac{2\pi r}{v} = \frac{2\pi}{\eta B} \quad \cdots\cdots (8)$$

Accordingly, a uniform magnetic flux density provides a constant period, τ, and all the electrons emitted at a given time return to the original point P simultaneously, i.e., the angular velocity is always constant.

When an electron is emitted obliquely with respect to the lines of magnetic force in a uniform magnetic field, the electron forms a helical orbit, a phenomenon attributable to a uniform motion along the lines of magnetic force and a circular motion perpendicular to the lines of magnetic force. As shown in Fig. 7.1-4, when an electron is emitted from point P at a velocity v and at an angle α with respect to the direction of the uniform magnetic field H, the electron travels along helical orbit a. This is due to a uniform motion caused by the velocity component v_x and a circular motion caused by the velocity component v_y. The electron then passes through point P′ on the line of magnetic force containing the original point, P. Since $v_y = v \sin \alpha$, the radius r of the circular orbit can be rewritten as follows:

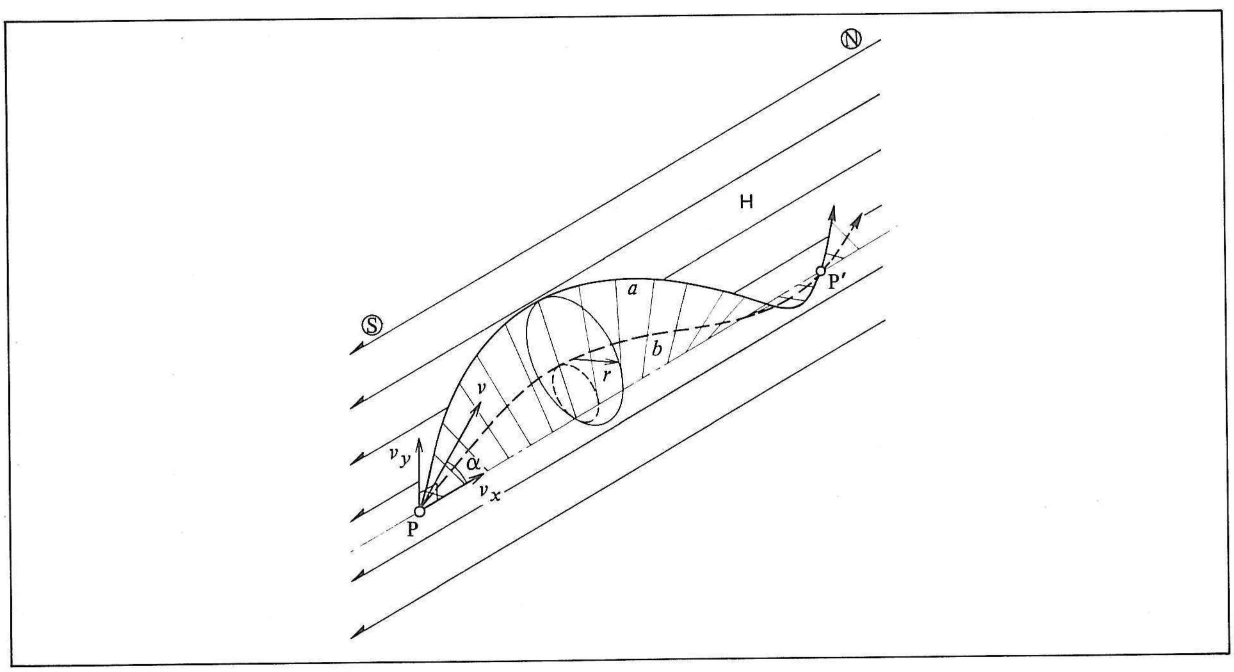


Fig. 7.1-4 Trajectories of electrons emitted obliquely in a uniform magnetic field

$$r = \frac{v}{\eta B} \sin \alpha \quad \cdots\cdots (9)$$

In electron microscopes, since electron beams near the axis are generally used for foming an image, α is extremely small. Therefore, the velocity component of an electron parallel to the lines of magnetic force can be given as follows:

$$v_x = v \cos \alpha \fallingdotseq v \quad \cdots\cdots (10)$$

When two electrons are emitted simultaneously from point P at different angles, they orbit a and b and reach point P′ at the same time. That is, it is possible to form an image in a uniform magnetic field. Distance d, between points P and P′ on the same line of magnetic force, is the distance between nodal points and is calculated as follows:

$$d = v_x \tau = \frac{2\pi v}{\eta B} \quad \cdots\cdots (11)$$

When this equation is compared with Equation (7), it will be found that d is equal to the circumference of the circular orbit described by an electron having a velocity v perpendicular to the line of magnetic force. Fig. 7.1-5 shows the orbits of electrons in a vacuum. All the electrons emitted from the same point, P, converge at the same point, P′, through respective paths. The effect of this is similar to that of optical convex lenses. However, there is an obvious difference in that all parallel light rays which are incident to an aberration-free optical lens converge on the back focal plane, whereas electrons emitted in a uniform magnetic field do not converge.

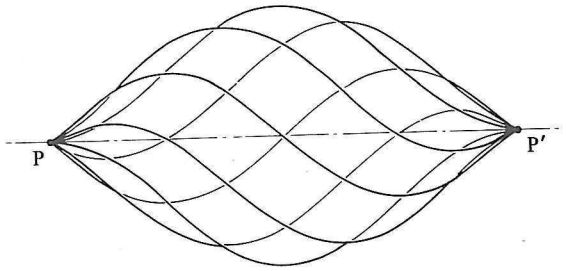


Fig. 7.1-5 Electrons passing through a uniform magnetic field

There are three types of magnetic lenses in use: (1) a multi-layer coil, i.e., an air-core solenoid coil (refer to Fig. 7.1-6a), (2) a coil enclosed by soft iron plates (in order to reduce leakage flux) containing a gap (in order to concentrate the induction field) (refer to Fig. 7.1-6b), and (3) a coil enclosed by soft iron plates containing a gap and internal soft iron pole pieces (in order to ensure a high intensity magnetic field) (refer

to Fig. 7.1-6c). Almost all modern electron microscopes use pole pieces for high resolving power and high magnification. The function of such an electron lens is more or less the same as that of horse-shoe magnets symmetrically arranged about an axis. Accordingly, all the parallel electron beams incident to the curved magnetic field converge at one point.

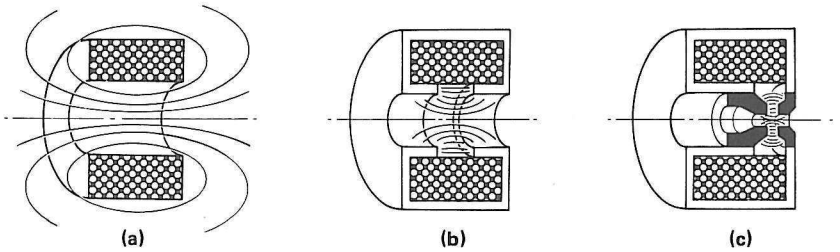


Fig. 7.1-6 Types of magnetic electron lenses

Fig. 7.1-7 shows the trajectory of an electron passing through such a magnetic field. Although the electron beam path in a magnetic lens is not the same as the light ray path in an optical lens, the results are similar. As shown in Fig. 1.8, the electron travels rectilinearly, crosses the axis, moves through the magnetic field along a spiral orbit, approaches the axis, crosses the axis again, and travels rectilinearly. This effect is similar to the converging action of an optical convex lens, and if the revolution of the electron about the axis is omitted, the converging action of an electron lens can be considered to be identical to that of an optical lens.

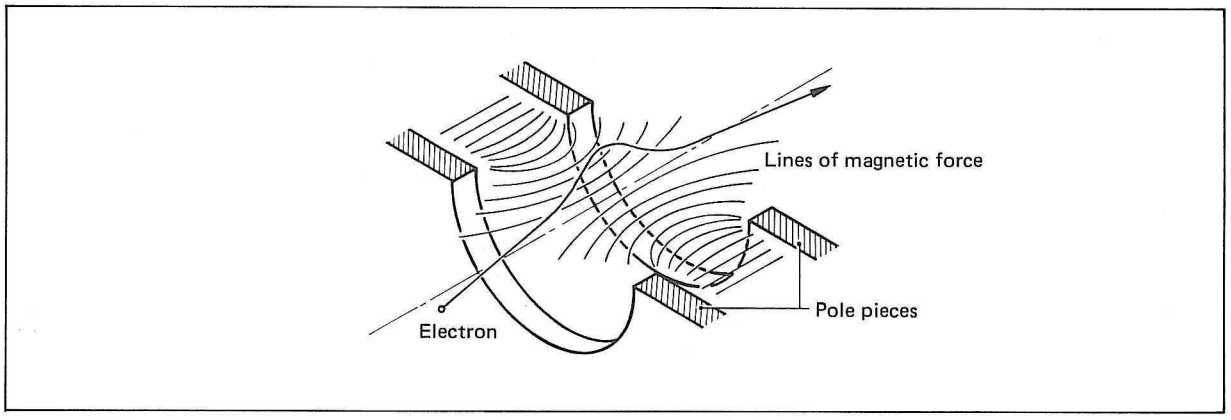


Fig. 7.1-7 Electrons passing through magnetic lens

A magnetic lens containing pole pieces magnetized to near-saturation for concentrating magnetic

flux in a very narrow space constitutes a thin lens. The magnetic field distribution and image formation graphs are illustrated in Fig. 7.1-8. The focal length f and rotation angle θ are given as follows:

$$\left.\begin{aligned} \frac{1}{f} &= \frac{\eta}{8V}\int_{-\infty}^{+\infty} B^2(x)\,dx \\ \theta &= \sqrt{\frac{\eta}{8V}}\int_{-\infty}^{+\infty} B(x)\,dx \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (12)$$

where V: Accelerating voltage

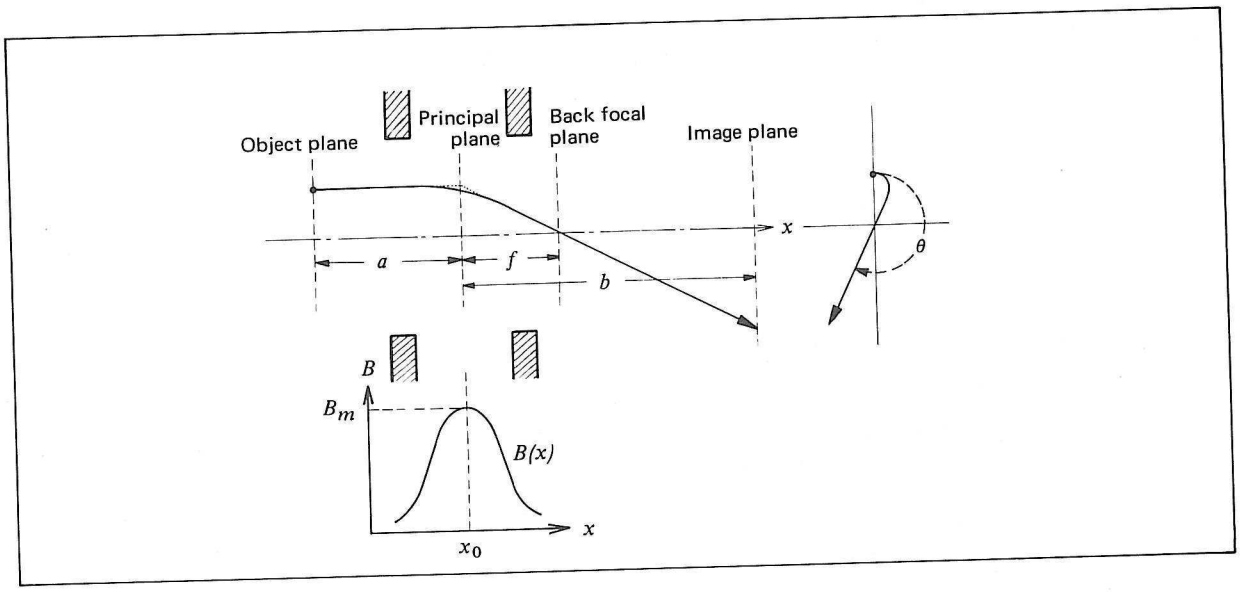


Fig. 7.1-8 Magnetic field distribution and image formation graphs

As known from Equation (12), shortening focal length f requires an increase in magnetic flux density B; moreover, since $B \propto NI$ (ampere-turns), current for the coil must be increased to obtain a short focal length. Since the aforementioned electron lens has the same effect as an optical thin convex lens, the following equations are obtained:

$$\left.\begin{aligned} \frac{1}{a} + \frac{1}{b} &= \frac{1}{f} \\ M &= \frac{b}{a} \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (13)$$

where M: Magnification

7.1.4 Interaction between electron beam and substances

When an electron beam passes through a substance, the beam is scattered due to coulomb interactions, the direction of movement is changed and a partial energy loss takes place.

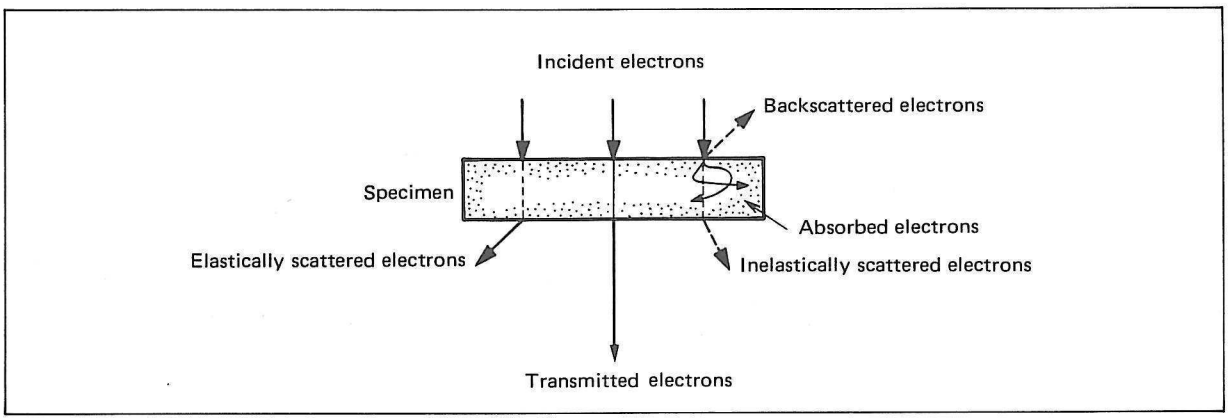


Fig. 7.1-9 Interaction between electrons and substances

As shown in Fig. 7.1-9, when electrons having a given energy impinge on a substance, they are changed into transmitted electrons, backscattered electrons (reflected electrons) and absorbed electrons (energy absorption) by the interaction of the aggregate of the atoms constituting said substance. The transmitted electrons can be classified into three types: 1) directly transmitted electrons (transmitted wave), which pass through the specimen with little change of direction or wavelength, 2) elastically scattered electrons (elastically scattered waves), which undergo a directional change due to atomic collision but retain their energy, and 3) inelastically scattered electrons (inelastically scattered waves) which undergo both a directional change and a partial energy loss.

The ratio of the directly transmitted electrons to that of elastically scattered electrons is related to the contrast of images in transmission electron microscopy. The contrast of amorphous specimen images is primarily determined by mass thickness. Images of crystalline specimens are largely influenced by Bragg reflection. Inelastically scattered electrons may cause chromatic aberration in the image formation process. The absorbed energy, i.e., the energy which scattered electrons have lost while passing through the specimen, results in excitation of the atoms and atomic nuclei in the specimen. This causes heating, magnetization, ionization, secondary radiation (secondary electrons, Auger electrons, X-rays and cathodoluminescence) and plasma oscillation. When an incident electron has high energy, part of the energy may sometimes cause radiation damage to the specimen by ejecting the atoms irreversibly from their normal positions in the specimen elastically. Although heat generation and ionization are the prime factors contributing to specimen

damage, they can be reduced by increasing the energy of the incident electrons. Backscattered electrons, which are sometimes called reflected electrons, scatter backwards with an energy comparable to the incident beam. The quantity of these electrons is determined by the specimen tilt angle and the atomic number of the element constituting the specimen.

7.1.5 Image formation and contrast

Image contrast is required in order to confirm the presence of an object and to study its configuration. If image contrast is unsatisfactory, it will be difficult to confirm the presence of an object, let alone study the configuration, even if the microscope has an extremely high resolving power. It therefore follows that the actual resolution of micrographs depends on image contrast to a very great extent.

In optical microscopy, image contrast is determined by the difference in the absorption coefficient at different points on the specimen and, to some extent, by the difference in reflectivity. However, in electron microscopy, image contrast is determined by scattering absorption contrast, diffraction contrast and phase contrast.

If the specimen is amorphous, the scattered electrons are absorbed by an aperture located near the back focal plane of the objective lens, thus producing scattering absorption contrast. This lens aperture has a very small diameter (several tens of μm) in order to minimize spherical aberration. Accordingly, if the scattering is large, most of the electrons will be blocked by the aperture, thus forming the dark portion of the image. The extent to which the electrons are scattered is proportional to the mass thickness of the specimen. Thus, the scattering absorption contrast provides information concerning the existence and configuration (topography) of the object as shown in Fig. 7.1-10.

In the figure, (a) shows the principle of contrast generation, (b) illustrates contrast generation in a specimen stained by a high density material (e.g., uranyl acetate or phosphotungstic acid), (c) shows an example of oxide film taken from the surface of a metallic specimen, and (d) shows an example of the shadow-casting technique, where a high density material is evaporated obliquely onto the replica film. Biological specimens are usually prepared by microtome sectioning and image contrast is obtained by directly staining the cellular tissue with osmium tetroxide, lead hydroxide, or uranyl acetate both before and after embedding or sectioning. Micro-specimens, such as viruses and cells, are usually processed by negative staining or by metal shadowing. The freeze-etching replica method is generally used in order to observe the cell surface and cell sections.

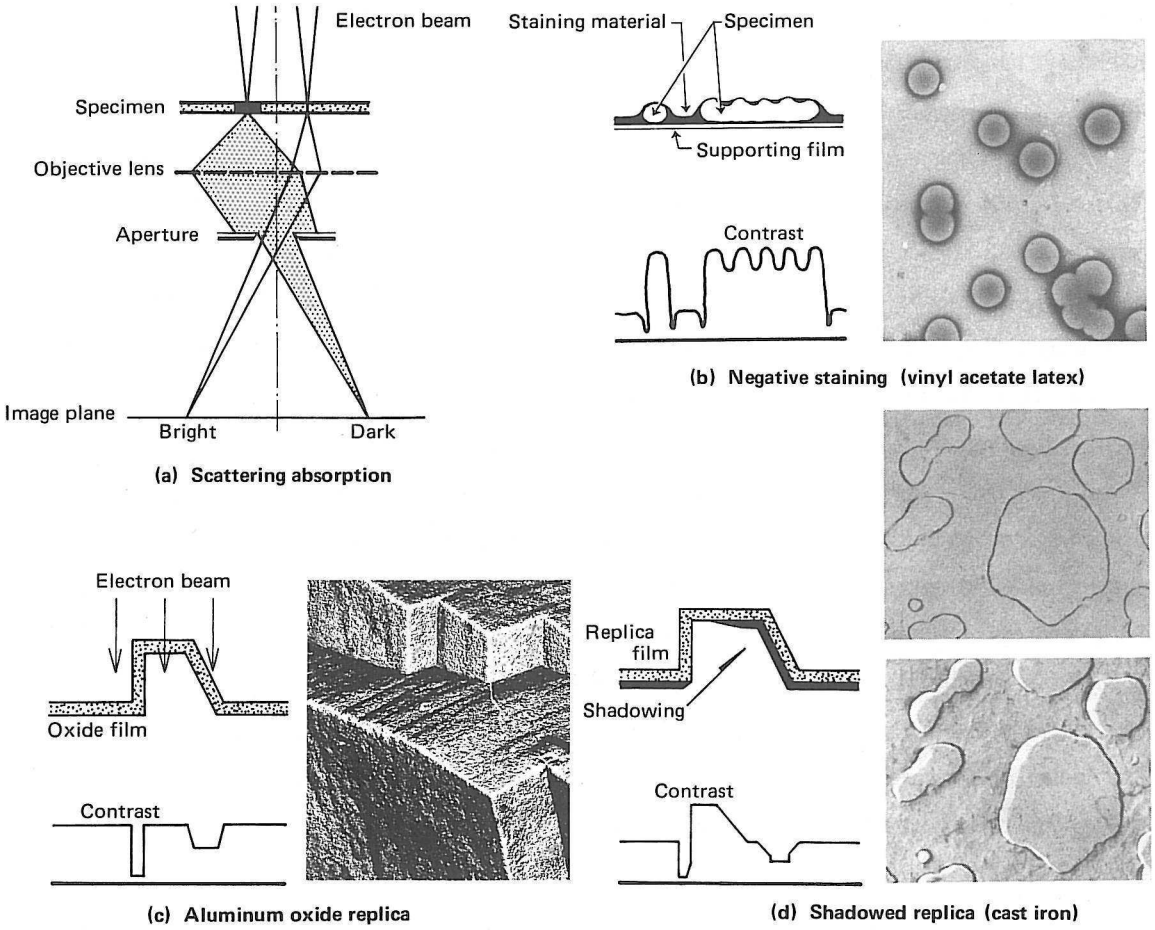
In the case of crystalline specimens, diffraction contrast appears as discussed below. If the atomic net planes in the crystal satisfy the following equation (Bragg equation):

$$2d \sin\theta = n\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

where d: Interplanar spacing
θ: Grazing angle of incidence (Bragg angle)
n: Integer (0, 1, 2, 3 . . .)
λ: Wavelength of the incident electrons,

a diffracted beam results.

Since the spacing corresponding to the minimum Bragg angle of a simple metal or ionic crystal is approx. 0.5 nm, the diffraction angle 2θ, which is the angle subtended by the direction of incident electrons (incident waves) and that of the diffracted electrons (diffracted waves), is usually 5×10^{-3} rad or more. Accordingly, since almost all the Bragg-reflected electrons (namely, diffracted waves) are obstructed by the aperture, contrast as shown in Fig. 7.1-11a occurs. This image is known as "bright field image". On the other



(a) Scattering absorption

(b) Negative staining (vinyl acetate latex)

(c) Aluminum oxide replica

(d) Shadowed replica (cast iron)

Fig. 7.1-10 Scattering absorption (mass thickness) contrast

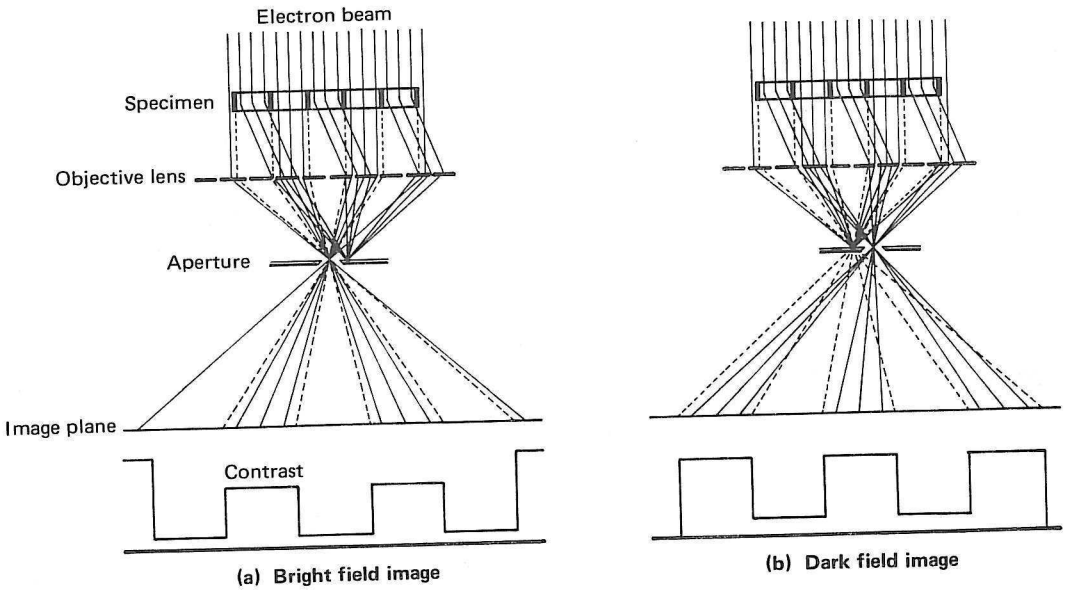


Fig. 7.1-11 Contrast in crystalline specimens

hand, when the aperture is shifted to obstruct the transmitted waves, so as to form an image by diffracted waves as shown in Fig. 7.1-11b, a so-called "dark field image" results. That is, dark field image contrast is usually achieved by inverting the contrast of the bright field image, except in cases where the crystal is very thick. If the crystal is curved, the reflection condition cannot be satisfied simultaneously over the entire area of the specimen.

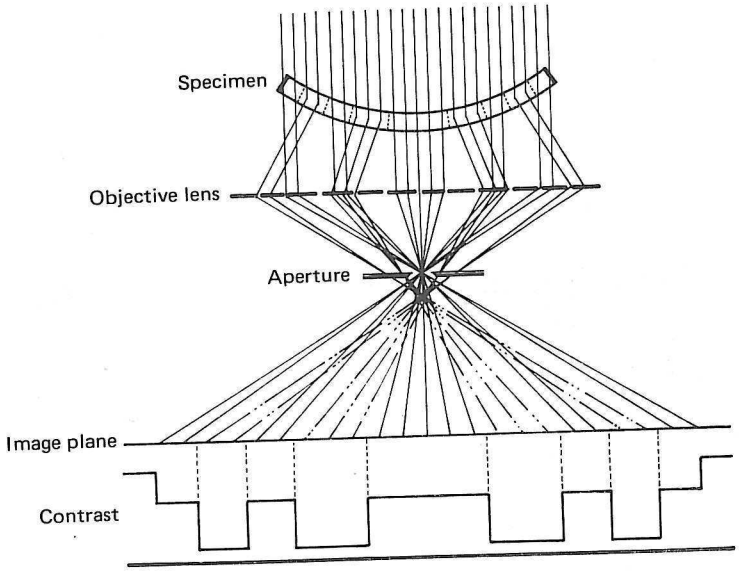
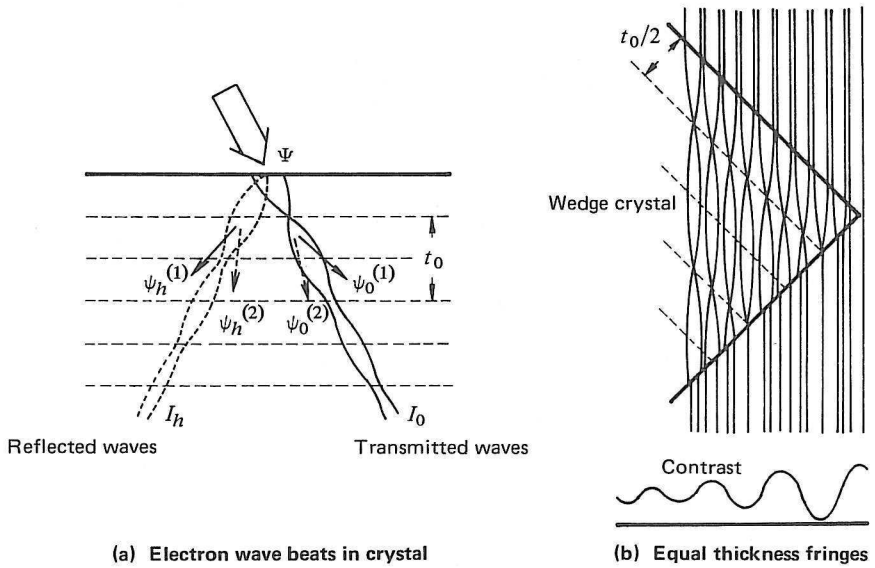


Fig. 7.1-12 Formation of equal inclination fringes

As a result, a fringe pattern, referred to as an "equal inclination fringe", appears as shown in Fig. 7.1-12. Electron beam illumination of a wedge crystal results in a fringe contrast referred to as an "equal thickness fringe". However, when the crystal takes the form of an exact cube (e.g., an MgO crystal), the reflection condition is satisfied over the entire area of the specimen. In this case, the entire crystal (according to simple kinematic theory) should be uniformly bright or dark. Fringe systems are recognized as follows:

When an incident wave Ψ enters a crystal, it is reflected at an atomic net plane having an index (hkl). Therefore, the intensity of the wave ψ_0 in the direction of the incident wave is decreased, and the intensity of wave ψ_h in the reflection direction is increased. The wave travelling in the reflection direction is reflected again at the atomic net plane $(\bar{h}\bar{k}\bar{l})$, and then advances in the original direction, increasing the intensity of the waves in the incident direction. Such intensity variation occurs repeatedly during passage through the crystal causing wave beats. Depth t_0, corresponding to the beat period, is called the "extinction distance" which depends upon the crystal, reflecting plane and the wavelength of the incident wave. The beat period of the reflected wave is delayed by a half period, compared with that of the transmitted wave. As illustrated in Fig. 7.1-13a, above effect is caused by the interference of two transmitted plane waves $\psi_0^{(1)}$ and $\psi_0^{(2)}$, and two reflected plane waves $\psi_h^{(1)}$ and $\psi_h^{(2)}$ which are slightly different in direction and wavelength, respectively. When electrons are scattered by atoms, not only elastically scattered waves but also inelastically scattered waves are generated. When an electron penetrates far into a crystal, the beat amplitude (intensity) decreases. The influence of inelastic scattering forms a background at the amplitude nodes. Therefore, in the case of a wedge crystal (illustrated in Fig. 7.1-13b), intensity I_0 is equivalent to the beat cutting section of wave ψ_0



(a) Electron wave beats in crystal (b) Equal thickness fringes

Fig. 7.1-13 Dynamical effect of electron waves

travelling in the incident direction. As a result, thickness fringes appear.

A crystal containing lattice imperfections provides a special contrast according to type (i.e., dislocations, stacking faults, voids, inclusion, etc.). When different types of precipitate exist, these lattice imperfections also result in special contrast. Since specimens contain a combination of these factors, complicated pattern contrasts are produced.

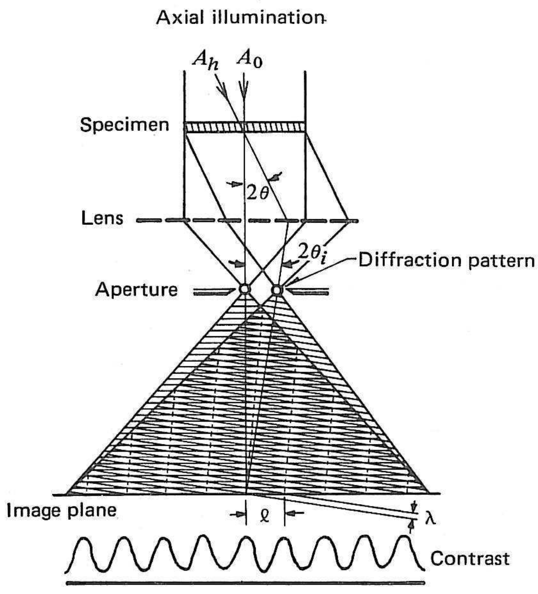
The contrast of extremely thin, small particles or low density specimens is determined mainly by phase contrast, instead of by scattering and absorption contrast. When electron waves of high coherence pass through a specimen, the phase of the waves becomes irregular due to scattering, lens aberrations, incorrect focusing and the internal potential of the substance. As a result, the intensity of the image forming waves on the image plane varies, a phenomenon which is referred to as phase contrast. Since phase contrast does not precisely correspond to the structure of the specimen, attention should be directed to the interpretation of the image obtained. Usually, the clearest images are obtained at slightly underfocus. In this case, the degree of under-focus is determined according to the substance and magnification used. However, excessive under-focus may cause misinterpretation of the image owing to the influence of Fresnel fringes.

Atoms in a crystal form a periodically regular lattice structure and, if the reflection condition is satisfied, the relation in Equation (14) will exist between spacing d (this value is very small as mentioned above), wavelength λ of the incident electrons and the grazing angle of incidence θ. Contrast formation different from that due to scattering and absorption may occur in images whose specimens have the aforesaid structure. That is, the interference of two or three waves, such as the reflected wave A_h and the transmitted wave A_0, or other reflected waves, causes a fringe pattern known as the lattice image. Fig. 7.1-14a illustrates the process of pattern formation: Electron beams are emitted along the axis, Bragg-reflected at the thin film crystal specimen, and the reflected and transmitted beams passing through the aperture overlap on the image plane, making a periodic pattern. In the figure, the distance ℓ between the adjacent interference fringes is given as follows:

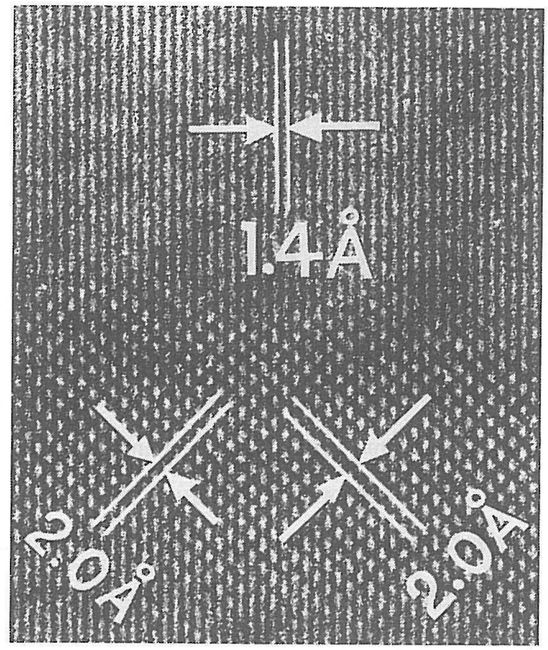
$$\ell = \frac{\lambda}{2 \sin \theta_i} = \frac{\lambda}{2 \sin \theta} M = M \cdot d \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (15)$$

where M: Magnification

As shown in this equation, ℓ is equal to the atomic net plane spacing multiplied by the magnification. Accordingly, this value is usually employed to represent the resolving power. However, lattice patterns are generally not greatly influenced by specific aberrations; this is especially so in the case of patterns obtained by tilted illumination. The actual interference fringes are complicated by other factors, such as crystal thickness, deviation from the Bragg condition, incorrect focusing, dislocation and secondary and tertiary diffracted waves. Fig. 7.1-14b illustrates the lattice pattern of a single crystal of gold. Diffracted waves from planes (220)



(a) Interference of two waves by axial illumination



(b) Lattice pattern showing single gold crystal planes (220) and (200)

Fig. 7.1-14 Image of specimen having periodic structure

and (200) are introduced through a lens aperture to form two interference fringe systems (0.14nm and 0.2nm) whose spacings are equal to the respective spacings of the lattice planes. Simultaneous use of the waves reflected by the rear plane in the case of axial illumination, in addition to the aforesaid waves, yields a half period pattern.

When an electron beam is incident with respect to two overlapping crystals, interference of the transmitted and double diffracted waves from the specimen results in a periodic pattern referred to as a "Moiré pattern". There are two fundamental types of Moiré pattern; one is the parallel pattern shown in Fig. 7.1-15b and the other is the rotation pattern shown in Fig. 7.1-15c. The parallel pattern is caused by double diffraction in the overlapped crystals, A and B, whose spacings, d_a and d_b, differ slightly. Satellite m and direct spot o are used through an aperture for Moiré pattern formation. On the other hand, the rotation pattern results from double diffraction in overlapped crystals having equal spacings but whose net plane directions differ (rotation angle α).

Spacing d_m for the parallel pattern is given as follows:

$$d_m = \frac{d_a d_b}{d_a - d_b} \quad \cdots\cdots (16)$$

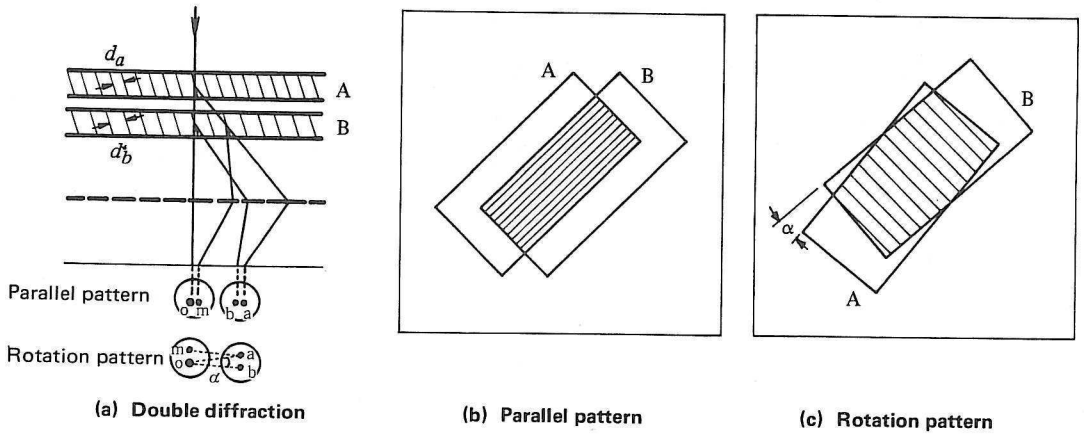
The spacing for a rotation pattern when $d_a = d_b = d$ is:

$$d_m = \frac{d}{\alpha} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (17)$$

The spacing for mixed pattern is calculated as follows:

$$d_m = \frac{d_a\, d_b}{\sqrt{(d_a - d_b)^2 + d_a\, d_b \cdot \alpha^2}} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (18)$$

The Moiré patterns of specimens become complicated by lattice imperfections, such as dislocation.



(a) Double diffraction (b) Parallel pattern (c) Rotation pattern

Fig. 7.1-15 Formation of Moiré patterns by double diffraction

7.1.6 Electron diffraction

Like X-rays, electron beams are reflected (diffracted) at the net plane of a crystal lattice, a factor which can be utilized in the study of crystal structures. There is a close relation between electron diffraction patterns and electron microscope images. That is to say, electrons scattered by a specimen provide Fraunhofer diffraction patterns at the back focal plane of the electron lens which are in turn Fourier-transformed so as to form electron microscope images. Accordingly, the structure of the specimen can be examined by correlating the diffraction patterns and the microscope images.

However, since there are a number of differences between electrons (charged particles) and X-rays (electromagnetic waves), they cannot be treated in the same way. The wavelength of an electron, for example, is very much shorter than that of an X-ray; approximately 1/40 in fact. That is to say, the wavelength of a 100 keV electron beam is 0.0037 nm, while that of a characteristic X-ray of the CuKα line is about 0.154 nm. As a result, the radius ($1/\lambda$) of the Ewald reflection sphere increases to the extent that it can be assumed that part of the sphere is a plane. Accordingly, by using a reciprocal lattice, a diffraction pattern can be analyzed fairly simply. Electron beams, as mentioned above, interact with substances to a far greater extent than in the case of X-rays. In other words, the scattering power (diffraction wave amplitude/incident wave amplitude) of electron beams is far greater (10^6 times or more) than that of X-rays. As a result, small specimens are able to yield clear diffraction patterns. That is to say, film with a thickness of 50 nm or less, crystallites, gases, etc. can be effectively studied by electron beam diffraction. However, when the crystal thickness is increased, dynamical effects cannot be disregarded in the case of electron diffraction. Generally, the identification of a substance in an electron diffraction pattern is accomplished by comparing said substance with the available X-ray diffraction data. Furthermore, electron diffraction is used to estimate the orientation of a crystal and the size and shape of a crystallite from the shape and structure of the pattern. Another factor is that since electrons are charged particles, their paths can be easily altered by the effect of magnetic or electrostatic fields. Consequently, a variety of diffraction methods for the selection of high resolution, selected area and high dispersion is possible.

When incident electron waves are scattered by atoms in a substance, the waves expand spherically from the center of the atoms. Moreover, when the specimen is in a crystalline state, having a regular three-dimensional arrangement of atoms, a constant phase relationship exists between the waves emitted from the respective atoms. These waves travel in one direction only and are mutually coherent (coherent elastic scattering). This is known as the "Bragg reflection". As shown in Fig. 7.1-16a, waves are reflected by the atomic net planes. If the path difference, $2d \sin \theta$, (shown by the thick lines in the figure) is equal to $n\lambda$ (where n is an integer, and λ is the wavelength), the waves reflected at successive planes will be in phase. Thus, Equation (14), $2d \sin \theta = n\lambda$, is obtained.

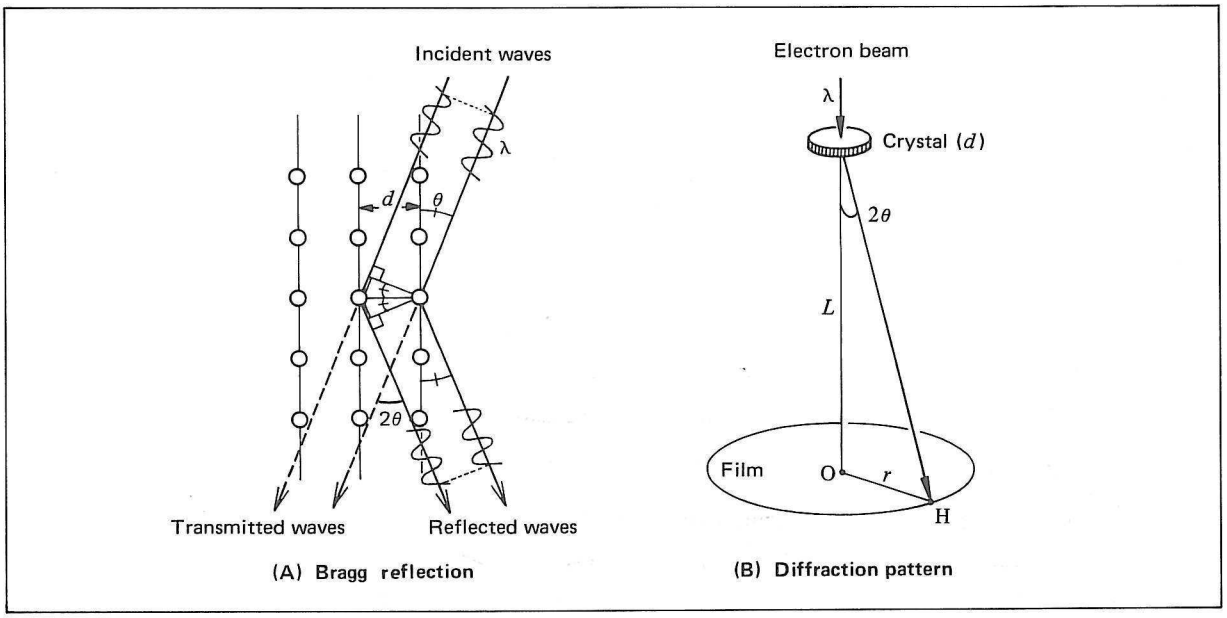


Fig. 7.1-16 Electron diffraction

When an electron microscope is used as an electron diffraction apparatus, the equation, $n = 1$, is changed as follows, since the Bragg angle for high-velocity electron beams is very small ($\sin\theta \fallingdotseq \theta$).

$$d2\theta = \lambda \quad \cdots\cdots (19)$$

In Fig. 7.1-16b, O is the center spot, H is the diffraction spot (or a point on the ring), and L is the distance between the crystal and the film (camera length). Thus, r, the distance between O and H, can be expressed as follows:

$$r = L2\theta \quad \cdots\cdots (20)$$

From Equations (19) and (20),

$$rd = L\lambda \quad \cdots\cdots (21)$$

In the above equation, if r is known and $L\lambda$ is obtained by using a known standard specimen, the unknown specimen (d) can be determined by using the same test conditions. When a thick single crystal specimen is observed by transmission electron diffraction, or when a single crystal specimen is observed by reflection electron diffraction, a band pattern (Kikuchi pattern) made up of pairs of white and black parallel lines, appears. This pattern is generated by the diffraction of the wave which has already been inelastically scattered in the crystal. By using this method, the interplanar spacing can be obtained.

Electron diffraction of a specimen micro-area can be executed by using a lens system of two or more stages. Fig. 7.1-17 shows the principle of selected area electron diffraction. In the figure, parallel electron beams impinge on specimens S_1 and S_2 and diffracted waves from the specimens produce diffraction patterns

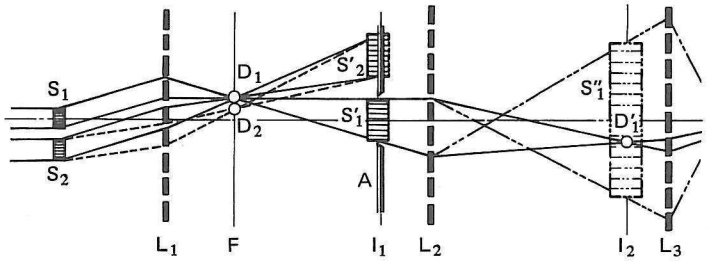


Fig. 7.1-17 Selected area electron diffraction

D_1 and D_2 at the back focal plane F of the objective lens L_1 so as to form magnified images S'_1 and S'_2 on the image plane I_1. When aperture A is inserted into the image plane I_1, in order to limit the field of view to the size of S'_1, only the electron beams passing through aperture A, i.e., the electrons from specimen S_1, are used to form the next stage image or diffraction pattern. When F or I_1 is brought into focus by the next stage lens, L_2, the diffraction pattern D'_1 or the magnified image S''_1 is formed on image plane I_2. The third lens L_3 produces the final image. The camera length is fixed in the case of a two image-forming lens system, but is variable in the case of a three or more-stage system. Equation (21) applies to both systems. When using the electron diffraction method, errors may result from defocusing and spherical aberration. To minimize such errors, exact focusing must be achieved or the micro-beam diffraction method must be used instead of the aperture, thereby limiting the field. Furthermore, when correlating the diffraction pattern with the image, it is necessary to take the magnetic rotation of the imaging lenses into consideration. A needle-like crystal having a known crystal structure is convenient for this purpose.

7.2 Outline of structure

7.2.1 Electron gun

The illuminating (electron) source of an electron microscope must meet the following requirements: high brightness, small size, and high stability, including emitted electron velocity stability. There are several types of electron gun which meet these requirements. However, they are generally composed of 3 electrodes and thermionically activated as shown in Fig. 7.2-1a.

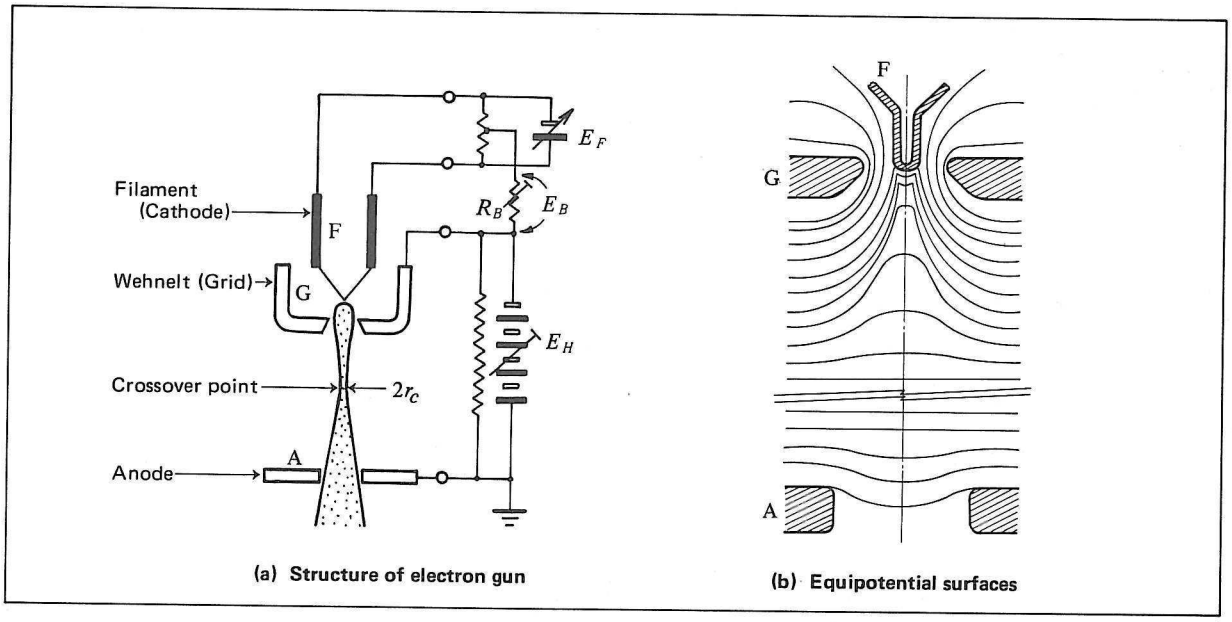


Fig. 7.2-1 Generation of electron beam

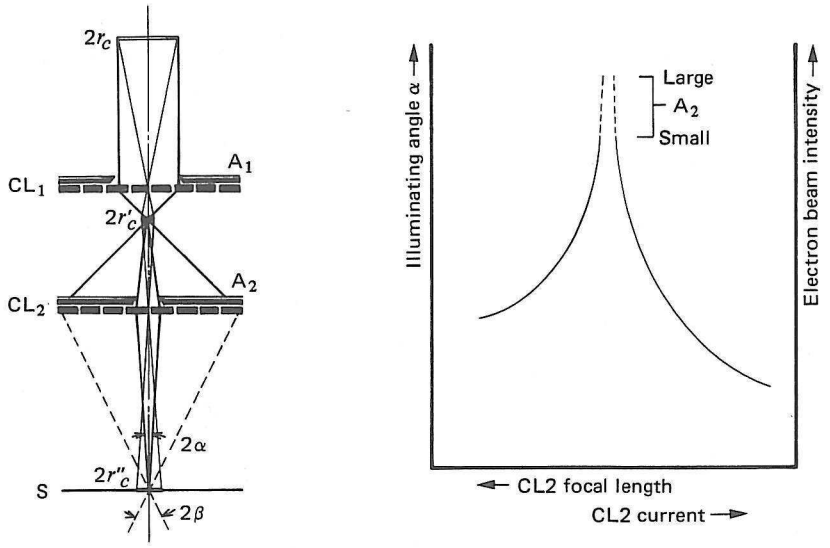
In the figure, the hot cathode F is usually a hairpin filament, but a point filament can also be used. A tungsten filament is usually employed owing to its suitable work function, high melting point, low vapor pressure, and high mechanical strength. However, a special type electron gun using LaB_6 and a field emission gun can also be used. The electrode G corresponds to the grid in a vacuum tube and is called a Wehnelt. The electrode A is an anode or plate. The characteristics of the source are determined by the shape and position of F, G and A, and the relation between their electric potentials. The JEM electron microscope uses a cool beam gun which satisfies the above-mentioned requirements.

When a negative high electric potential from the accelerating power source, E_H, is applied to the filament and a current from the heating power source, E_F, flows through the filament, thermionic electrons are emitted from the filament tip and its neighboring parts. The electrons are accelerated by the electric potential difference between the filament and anode. At the same time, a voltage drop by the bias resistance, R_B,

supplies a bias potential (self-bias) for the Wehnelt. In this case, the potential distribution between the respective electrodes, i.e., the equipotential surface, forms a kind of electrostatic cathode lens as shown in Fig. 7.2-1b. The electrons are concentrated to a point and emitted from that point. This electron converging point is called the "crossover point", and the minimum size of the point $2r_c$ is taken as the size of the source. The cool beam electron gun is designed to minimize the diameter of the crossover and to obtain high brightness, but with this type of gun, the filament position must be adjusted precisely; otherwise, performance will be adversely affected. The stability of the source is primarily achieved by negative feedback, using the self-bias method, but the stabilization of the power supply and countermeasures for micro-discharges must also be taken into account. When the filament is heated gradually, the quantity of the emitted electrons reaches its limit (saturation) in accordance with the space charge. The saturation point must be reached to provide the most stable source, but heating in excess of the saturation point will shorten filament service life.

7.2.2 Condenser lens

A condenser lens is required to converge the electrons emitted from the electron gun and to illuminate the specimen as desired. Since the field of view in high magnification microscopy is limited to a very small area (approx. $1\mu m^2$ at 100,000X), the illumination area must be small. If a wide area is illuminated, adverse effects will result; e.g., the specimen temperature will increase. To obtain a small illumination area, a double



(a) Double condenser lens (b) Relation between focal length and illuminating angle

Fig. 7.2-2 Electron beam illumination

condenser lens is necessary.

Fig. 7.2-2a shows the function of a two-stage condenser lens. In the figure, the size of the electron source $2r_c$ at the crossover point is converged to $2r_c'$ by the first stage condenser lens CL1 and the source is focused on the specimen plane S by the second stage condenser lens CL2 as shown by the source image $2r_c''$. A_1 and A_2 are apertures. The illuminating angle α near the axis is determined according to the diameter of A_2, i.e., the range designated by the broken lines (see Fig. 7.2-2b) is determined by A_2, and the maximum illuminating angle in this range is equal to the divergence angle β. If the source image $2r_c''$ is formed under or over the specimen plane S by changing the focal length of the second condenser lens CL2, the illuminating angle α will be reduced but the illuminated area will increase and the electron beam intensity will decrease, thereby resulting in a darker image.

The parallelism of the electron beam is perfect when $\alpha = 0$, but an allowable range of α is provided for in the design of the aperture. Except in special cases, the focus is formed near the specimen plane to illuminate the specimen evenly. Shortening the focal length of CL1 makes the source image smaller, thus narrowing the illumination area.

Furthermore, the JEM electron microscope contains an interlocking two-stage beam deflector immediately under the condenser lens. This deflector provides tilted beam illumination on the specimen in order to obtain a high resolution dark field image.

7.2.3 Specimen chamber

The specimen chamber of an electron microscope must satisfy the following requirements.

(1): The specimen chamber must contain a stage capable of quick and easy specimen exchange. The stage must hold the specimen or specimen holder firmly and must move smoothly when selecting the field of view. Two types of stage are available for the JEM: a top-entry stage and a side-entry stage. Either type is provided as standard. In high performance electron microscopes, external vibration, which adversely affects the resolving power, must be eliminated. The micro-field of view at high magnification must be selected correctly and a mechanism for the quick exchange of specimens is required to increase specimen throughput. Since the specimen exchange device of JEM electron microscopes contains an airlock mechanism, the specimen can be exchanged without breaking the column vacuum.

(2): The specimen chamber must be capable of accommodating many attachments in order to widen the scope of application. Moreover, to reduce specimen contamination and maintain a high vacuum, a cooling trap must be installed near the specimen. Also, untoward beam deflection must be almost completely eliminated.

7.2.4 Image forming lens system

The image forming system is normally composed of three lenses: an objective lens (OBJ), an intermediate lens (INT), and a projector lens (PROJ). In a high magnification lens system, a first-stage image is formed by the objective lens (of small aberration) located immediately below the specimen. The image is further enlarged by the intermediate lens, and the final image is formed on a fluorescent screen or film by the high-magnification projector lens.

Focusing is achieved by adjusting the objective lens excitation current. Because specimens are very thin and the aperture angle is very small, the thickness of a specimen is covered by the depth of field. Owing to high magnification, the depth of focus is quite large. If the image is correctly formed on the screen, the same focus image can be obtained regardless of the film position, except in extreme cases.

An aperture inserted near the back focal plane of the objective lens has two important functions: (1) to limit the electron beam aperture angle in order to minimize aberration, and (2) to remove scattered electrons and thereby enhance image contrast.

In an electron microscope system, the optical axes of the lenses must be aligned with each other and misalignment of the axes must be rectified simply and quickly. The JEM electron microscope is designed to meet these requirements.

7.2.5 Viewing chamber and camera chamber

Since images formed by the electron beam cannot be directly observed with the naked eye, they must be converted into light images in order to select the field of view and effect focusing. There are two conversion methods: one is by means of a fluorescent screen (metal plate containing phosphor, green or yellow, with high visibility), in which case, observation is made from the same side as the electrons travel; the other is by means of a transmission (TV) type screen, in which case the image can be observed from the opposite side. The latter is mainly used for small-sized electron microscopes. For easy observation of images on the fluorescent screen, the light emitting efficiency and resolving power of the screen must be high. All JEM electron microscopes use a fluorescent screen on which high quality phosphor is applied. For easier observation, binoculars with a clear field of view are installed to enlarge the image fomred on the screen.

The best way to record electron microscope images is to use direct photography with high resolving power film. Each JEM electron microcope includes a fully automatic camera, complete with a data recording device, and its speically designed automatic exposure mechanism ensures optimum exposure. Since this camera is equipped with an airlock mechanism, rapid film exchange can be executed without breaking the column vacuum.

FLOWCHARTS

Startup

(Sect. 5.2.1)

Cooling water tap ..... Open

↓

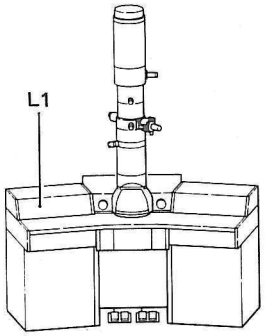
Distribution board switch ..... On

↓

POWER (L1) ..... START (5 sec) → ON

↓

READY (L1) ..... Wait until the lamp lights up



Shutdown

(Sect. 5.2.12)

FILAMENT (L1) ..... OFF

HT (L1) ..... OFF

Specimen holder ..... Remove

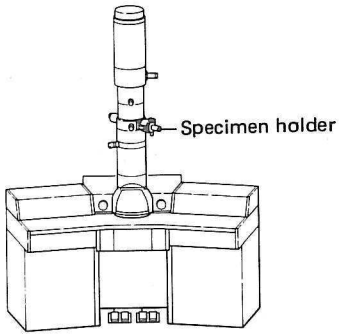
POWER (L1) ..... OFF

↓ Wait 10 minutes

Cooling water tap ..... Close

↓

Distribution board switch ..... Off



Routine operation (method C)

(Sect. 5.4)

Startup

READY (L1) ..... Check the lamp is on → Use of anticontamination device

HT (L1) ..... Press

BEAM CURRENT (L1) ..... Wait until reading stabilizes

Specimen and apertures ..... Remove from beam path

MAG2 (R1) ..... Press (5,000X)

FILAMENT (L1) ..... Stopper position

BEAM CURRENT (L1) ..... The reading increased

YES / NO → Finding the electron beam

Illumination appears on the screen when BRIGHTNESS (L1) is turned

YES / NO → Finding the electron beam

Focus illumination on the screen center with BRIGHTNESS (L1) and SHIFT (L1, R1)

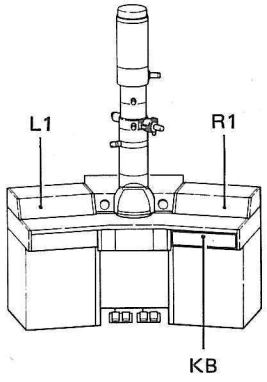
Insert a condenser lens aperture

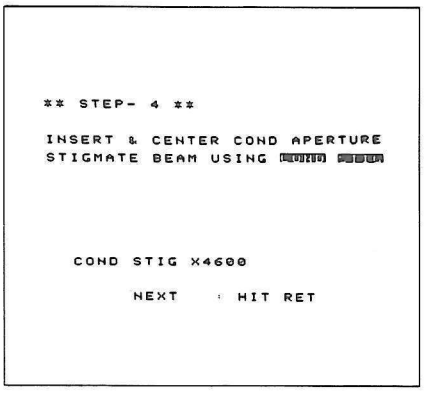
Correct condenser lens astigmatism

Roughly adjust the objective lens current

Insert a specimen and set the specimen tilt angle to zero

Accelerating voltage (kV)	BEAM CURRENT reading
80	40 ± 10%
100	50 ± 10%
120	60 ± 10%
160	80 ± 10%
200	100 ± 10%





Align the current center

Align the voltage center

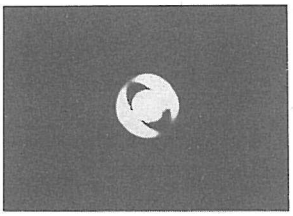
Insert an objective lens aperture

Carry out the S mode alignment

BRIGHT TILT (L1) ..... Off

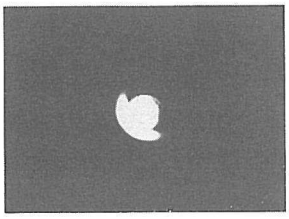
Focus illumination with BRIGHTNESS (L1)

Obtain filament image with FILAMENT (L1)



Filament image is symmetrical

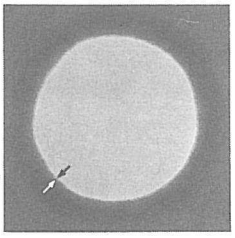
YES — NO



Make filament image symmetrical with GUN ALIGN: TILT (GA)

Turn FILAMENT (L1) until filament image shows no structures. Then set the stopper to the FILAMENT position.

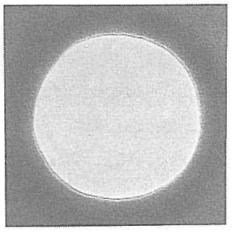
Obtain image at 50000× or higher, select a hole of about 5mm dia. and overfocus the image slightly (using binoculars).



Fringe spacing around the hole is even

YES — NO

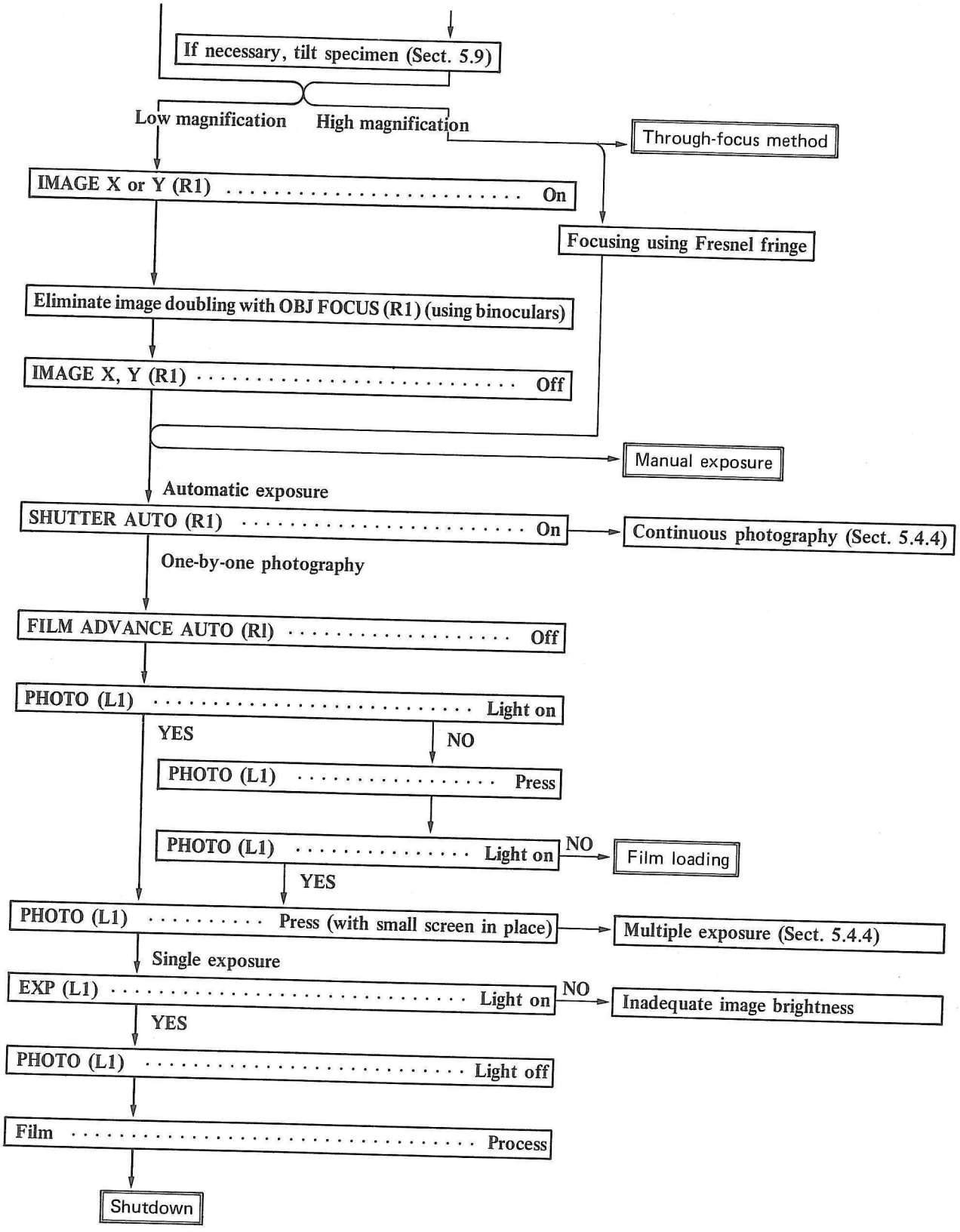
OBJ STIG1 (L1) ..... On



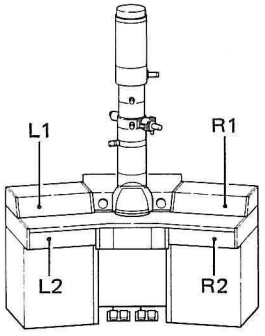
Make spacing even with DEF (L1, R1)

OBJ STIG1 (L1) ..... Off

Insert specimen and select field of view and magnification → Minimum exposure operation (MDS)


If necessary, tilt specimen (Sect. 5.9)
Low magnification
High magnification
Through-focus method
IMAGE X or Y (R1) ..... On
Focusing using Fresnel fringe
Eliminate image doubling with OBJ FOCUS (R1) (using binoculars)
IMAGE X, Y (R1) ..... Off
Manual exposure
Automatic exposure
SHUTTER AUTO (R1) ..... On
Continuous photography (Sect. 5.4.4)
One-by-one photography
FILM ADVANCE AUTO (RI) ..... Off
PHOTO (L1) ..... Light on
YES
NO
PHOTO (L1) ..... Press
PHOTO (L1) ..... Light on
NO
Film loading
YES
PHOTO (L1) ..... Press (with small screen in place)
Multiple exposure (Sect. 5.4.4)
Single exposure
EXP (L1) ..... Light on
NO
Inadequate image brightness
YES
PHOTO (L1) ..... Light off
Film ..... Process
Shutdown

Finding electron beam



Routine operation

BEAM CURRENT (L1) reading does not increase when FILAMENT (L1) is turned

V3 (PAGE-3) ..... Open

YES / NO

Evacuate camera chamber and wait until V3 opens

BIAS MODE ..... 70 – 80

FILAMENT (L1) ..... OFF → Stopper position

BEAM CURRENT (L1) ..... Reading increases

YES / NO

Electron gun filament replacement (Chap. 6)

Illumination appears on screen when BRIGHTNESS (L1) is turned — YES → Routine operation

NO

All lenses except PROJ (L2) ..... On

SHIFT (L1, R1) ..... Midpoint

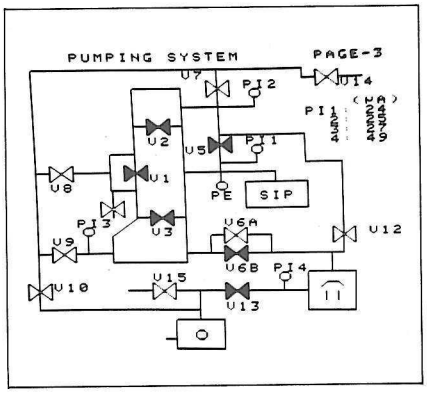
Illumination appears on screen when BRIGHTNESS (L1) is turned

YES / NO

GUN ALIGN: SHIFT (GA) ..... Midpoint

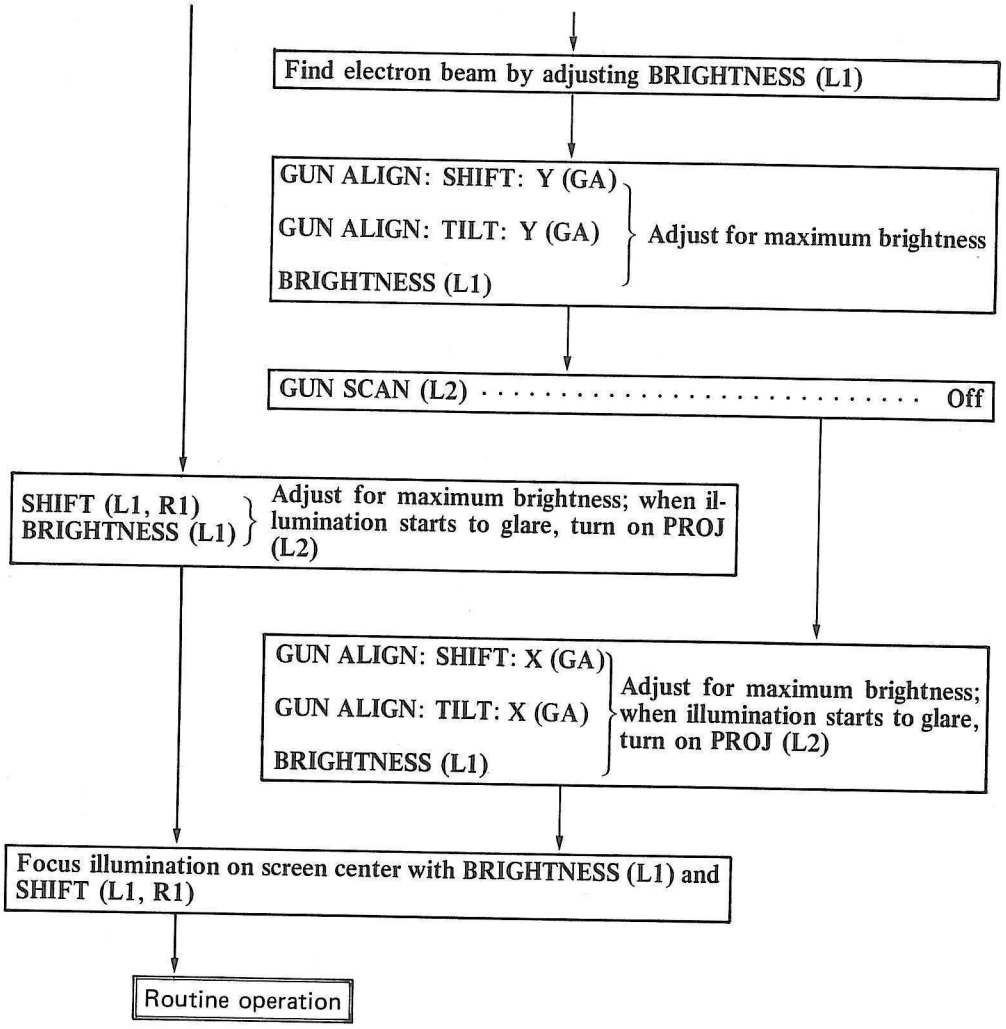
GUN ALIGN: TILT (GA) ..... Midpoint

GUN SCAN (L2) ..... On



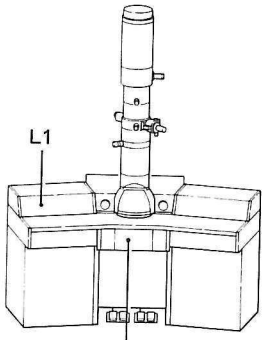
: Open

: Closed


Find electron beam by adjusting BRIGHTNESS (L1)
GUN ALIGN: SHIFT: Y (GA)
GUN ALIGN: TILT: Y (GA)
BRIGHTNESS (L1)
Adjust for maximum brightness
GUN SCAN (L2) ..... Off
SHIFT (L1, R1)
BRIGHTNESS (L1)
Adjust for maximum brightness; when illumination starts to glare, turn on PROJ (L2)
GUN ALIGN: SHIFT: X (GA)
GUN ALIGN: TILT: X (GA)
BRIGHTNESS (L1)
Adjust for maximum brightness; when illumination starts to glare, turn on PROJ (L2)
Focus illumination on screen center with BRIGHTNESS (L1) and SHIFT (L1, R1)
Routine operation

Film loading

(Sect. 5.2.2)



FILAMENT (L1) ..... OFF

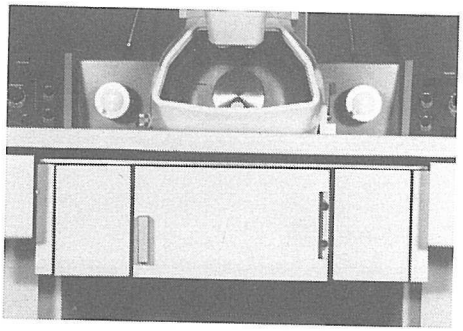
PHOTO (L1) ..... Check light off

↓

Camera chamber handle ..... Turn CW

↓ Wait about 15 min.

Camera chamber door ..... Opens



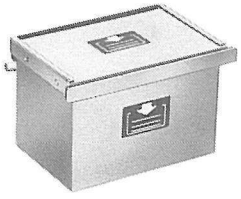
↓

Magazine stand ..... Draw out

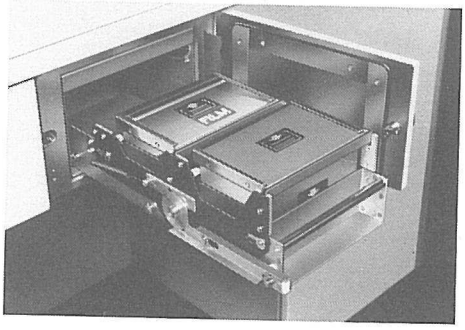
↓

Magazine (film) ..... Change

Dispensing magazine



Receiving magazine



↓

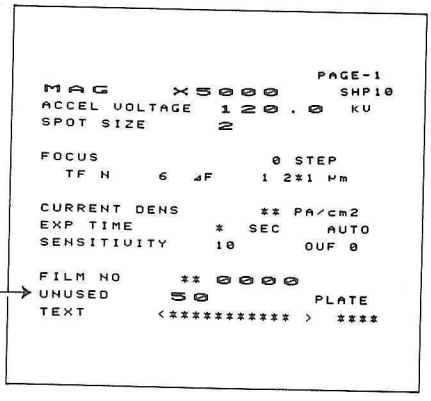
Camera chamber door ..... Close

↓

Camera chamber handle ..... Turn CCW

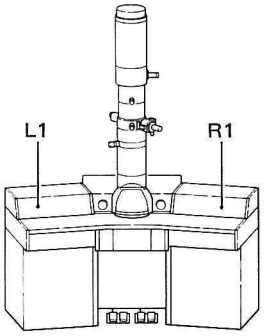
↓

UNUSED (PAGE 1) ..... Enter number of unused film sheets



Manual exposure

(Sect. 5.4.4)



Routine operation

SHUTTER AUTO (R1) ..... Off → Continuous photography (Sect. 5.4.4)

One-by-one photography

FILM ADVANCE AUTO (R1) ..... Off

EXP TIME (R1) ..... Enter required exposure time

PHOTO (L1) ..... Light on

YES

NO

PHOTO (L1) ..... Press

PHOTO (L1) ..... Light on → NO → No film (Change magazine)

YES

PHOTO (L1) ..... Press → Multiple exposure (Sect. 5.4.4)

Single exposure

EXP (L1) ..... Light on → NO → Inadequate exposure time

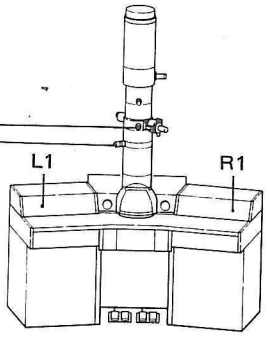
YES

PHOTO (L1) ..... Light off

Film ..... Process

Low magnification images

(Sect. 5.6.1)



Routine operation

Objective aperture ..... Remove
Field limiting aperture ..... Remove
LOW MAG (R1) ..... Press

Voltage center ..... Align

IMAGE X (R1) ..... On
OBJ STIG1 (L1) ..... On

OBJ FOCUS (R1) ..... Eliminate image doubling

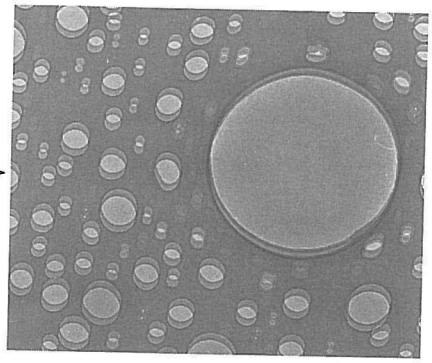


IMAGE X (R1) ..... Off
IMAGE Y (R1) ..... On

Image ..... Doubling

NO

YES

DEF (R1) ..... Eliminate image doubling

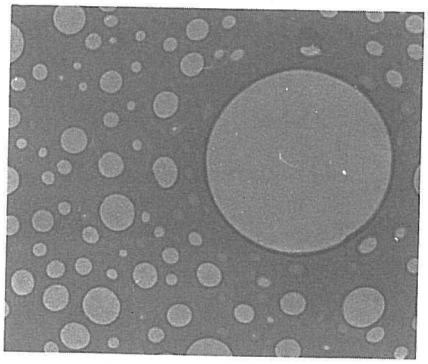


IMAGE Y (R1) ..... Off
IMAGE X (R1) ..... On

DEF (L1) ..... Eliminate image doubling

OBJ STIG1 (L1) ..... Off
IMAGE Y (R1) ..... Off

To increase image contrast, insert field limiting aperture

Dark field images

(Sect. 5.6.2)

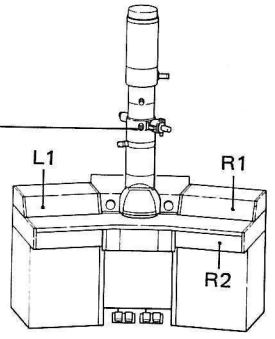
Routine operation

MAG1 (R1) ..... Press

Select magnification and field of view

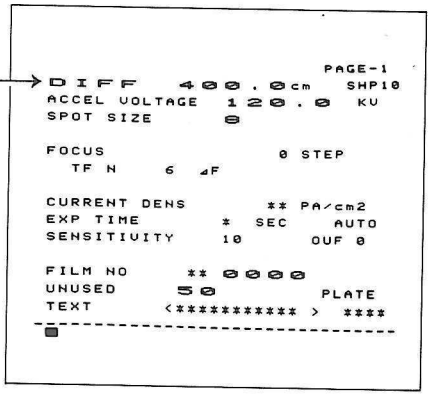
Objective aperture ..... Remove

DIFF (R1) ..... Press



BRIGHTNESS (L1) ..... Spread illumination

SELECTOR (R1) ..... Camera length 40 – 120cm



DIFF FOCUS (R1) ..... Focus diffraction pattern

PROJ ALIGN (R2) ..... Center direct spot on screen

DARK TILT (L1) ..... On

DEF (L1, R1) ... Center diffraction spot of interest on screen

Objective aperture ..... Center on screen

MAG1 (R1) ..... On

BRIGHT TILT (L1) ..... On

Dark field images

Bright field images

DARK TILT (L1) ..... On

Through-focus method

(Sect. 5.6.3)

Routine operation

OBJ 16X (R1) ..... off

Automatic exposure

SHUTTER AUTO (R1) ..... on

Manual exposure

SHUTTER AUTO (R1) ..... off

EXP TIMER (R1) ..... Set exp. time

THRU FOCUS (KB) ..... Press

U,O or space key (KB) ..... Press

Enter number of exposures (50 or less) and focus step (1 – 9) per film

RETURN (KB) ..... Press

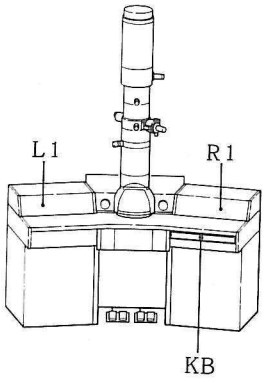
THRU FOCUS (KB) ..... Press

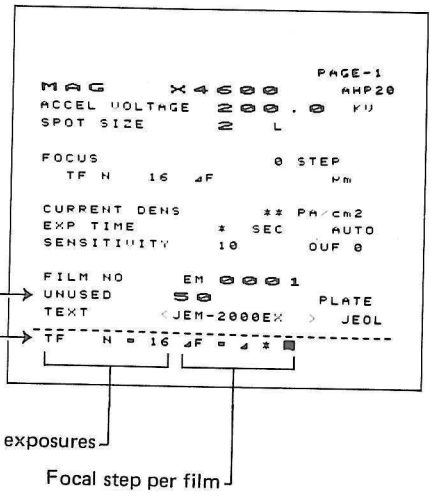
Image ..... Slightly overfocus

Unexposed films ..... More than required

Receiving magazine ..... Check for sufficient space

PHOTO (L1) ..... Press





Minimum exposure operation (MDS)

(Sect. 5.6.4)

Routine alignment

M, D, S, RETURN (KB) ..... Press

PHOTO MODE

Mag. and brightness for photographing ..... Set

Space key (KB) ..... Press

PAGE-1

Exposure time ..... Set

Space key (KB) ..... Press

PHOTO MODE

Blanking time ..... Set

RETURN or S (KB) ..... Press

SEARCH MODE

Mag. and brightness for searching ..... Set

N key (KB) ..... Select FOCUS or SEARCH

RETURN or F (KB) ..... Press

FOCUS MODE

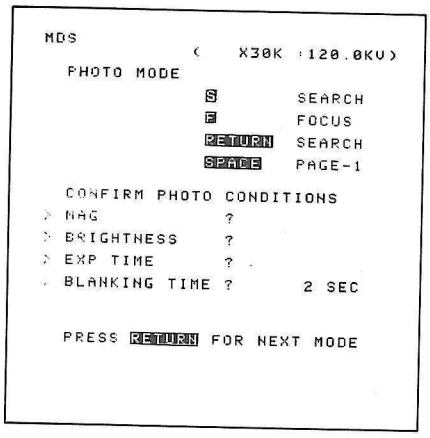
Magnification for focusing ..... Set

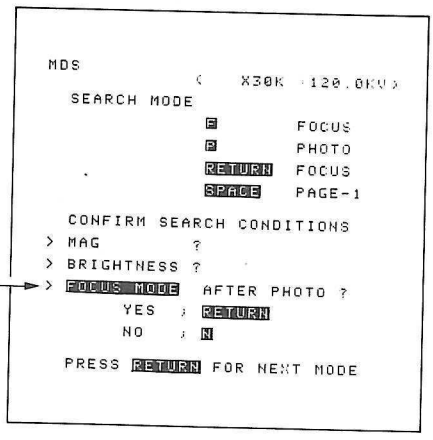
Conspicuous image ..... Center

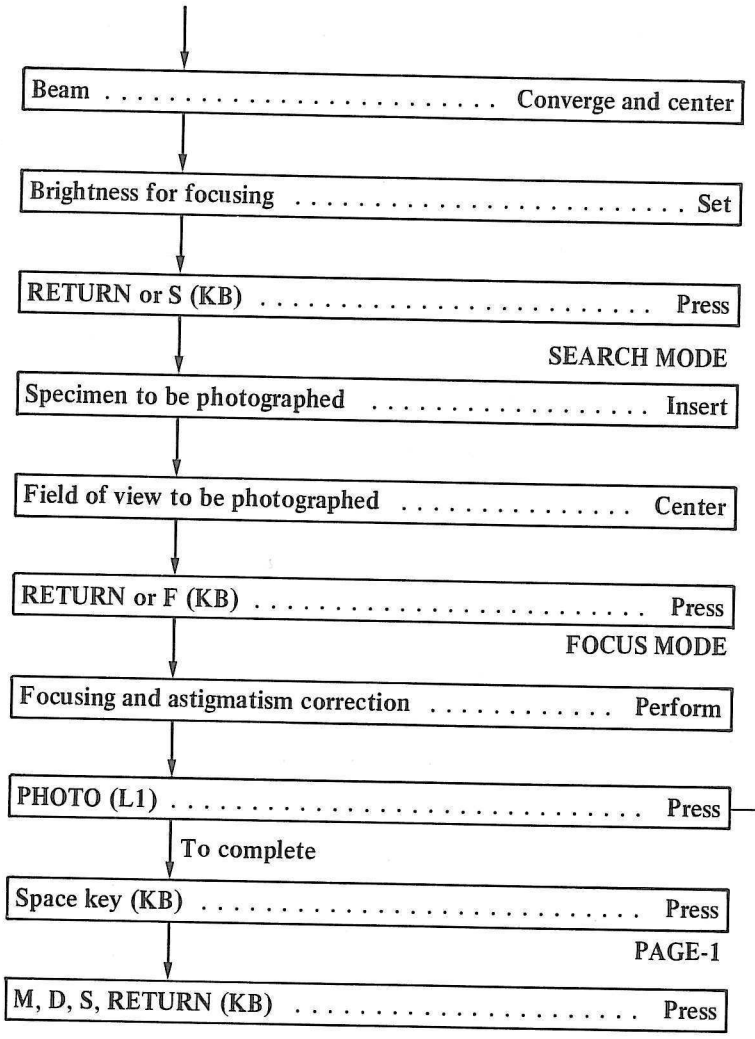
Use the specimen shift knobs.

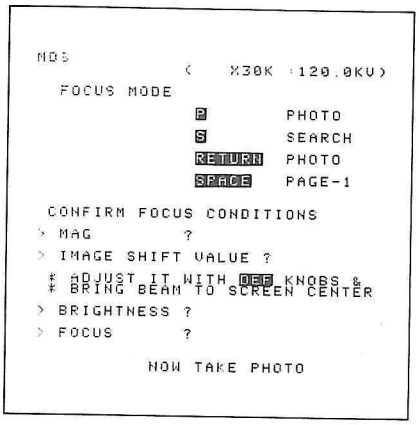
Conspicuous image ..... Out of screen

Use the DEFs (L1, R1).






Beam ..... Converge and center
Brightness for focusing ..... Set
RETURN or S (KB) ..... Press
SEARCH MODE
Specimen to be photographed ..... Insert
Field of view to be photographed ..... Center
RETURN or F (KB) ..... Press
FOCUS MODE
Focusing and astigmatism correction ..... Perform
PHOTO (L1) ..... Press
To complete
Space key (KB) ..... Press
PAGE-1
M, D, S, RETURN (KB) ..... Press
FOCUS MODE or SEARCH MODE
To repeat


MDS (X30K :120.0KV)
FOCUS MODE
P PHOTO
S SEARCH
RETURN PHOTO
SPACE PAGE-1
CONFIRM FOCUS CONDITIONS
> MAG ?
> IMAGE SHIFT VALUE ?
* ADJUST IT WITH DEF KNOBS &
* BRING BEAM TO SCREEN CENTER
> BRIGHTNESS ?
> FOCUS ?
NOW TAKE PHOTO

Selected area electron diffraction

(Sect. 5.7.1)

Routine operation

DIFF (R1) ..... Press

SELECTOR (R1) ..... Camera length 250 cm

DIFF FOCUS (R1) ..... Focus direct spot

PROJ ALIGN (R2) ..... Center direct spot on screen

Field limiting aperture ..... Insert

SAM ROCK (R1) ..... Press

Select field of view and magnification and roughly focus image

If necessary, record selected area image

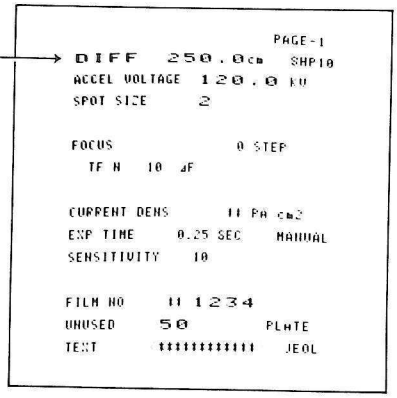
Objective aperture ..... Remove

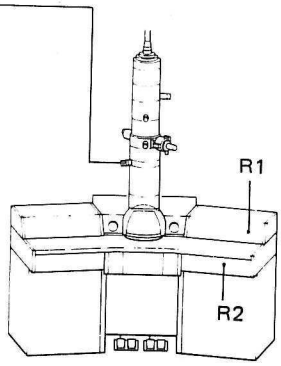
DIFF (R1) ..... Press

SELECTOR (R1) ..... Select camera length (10 – 250 cm)

DIFF FOCUS (R1) ..... Focus diffraction pattern

Record pattern (Manual exposure)



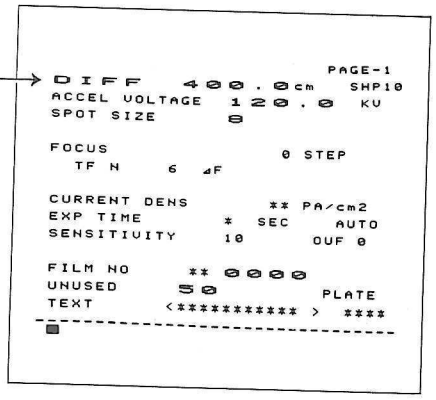


Microbeam electron diffraction

(Sect. 5.7.2)

Routine operation

Camera length ..... 250 cm



DIFF FOCUS (R1) ..... Focus direct spot

PROJ ALIGN (R2) ..... Center direct spot on screen

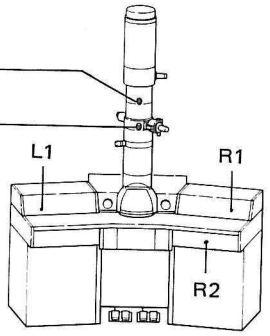
Select magnification in range of 4,000 to 500,000×, move the field of view of interest to screen center and focus image

Expose the entire field of view (1st exposure in double exposure)

Condenser aperture ..... Smallest

Objective aperture ..... Remove

SPOT SIZE (L1) ..... Minimum



BRIGHTNESS (L1) ..... Focus illumination

SHIFT (L1, R1) ..... Center illumination on screen

Expose the field of view of interest for diffraction (2nd exposure in double exposure)

Camera length ..... 10 cm

DIFF FOCUS (R1) ..... Focus diffraction pattern

Record diffraction pattern (manual exposure)

High dispersion electron diffraction

(Sect. 5.7.3)

Routine operation

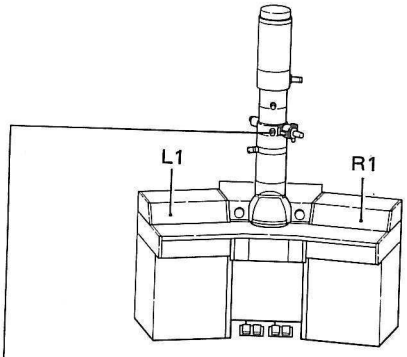
Select magnification and field of view and record

LOW MAG (R1) ..... Press

Magnification ..... ~ 500X

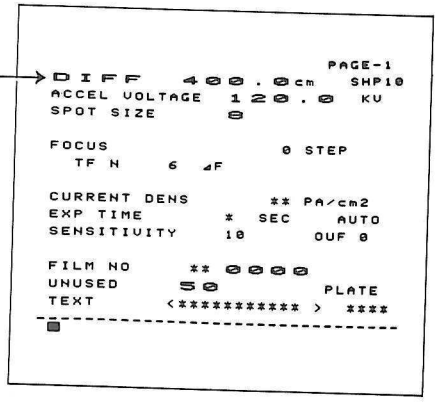
Field of view for diffraction ..... Center on screen

Select smallest objective aperture and center it on screen



If necessary, record the field for diffraction

Camera length ..... 400 cm or longer



Direct spot ..... on screen

YES

NO

BRIGHTNESS (L1) ..... Turn CCW

SHIFT (L1, R1) .. Center direct spot on screen

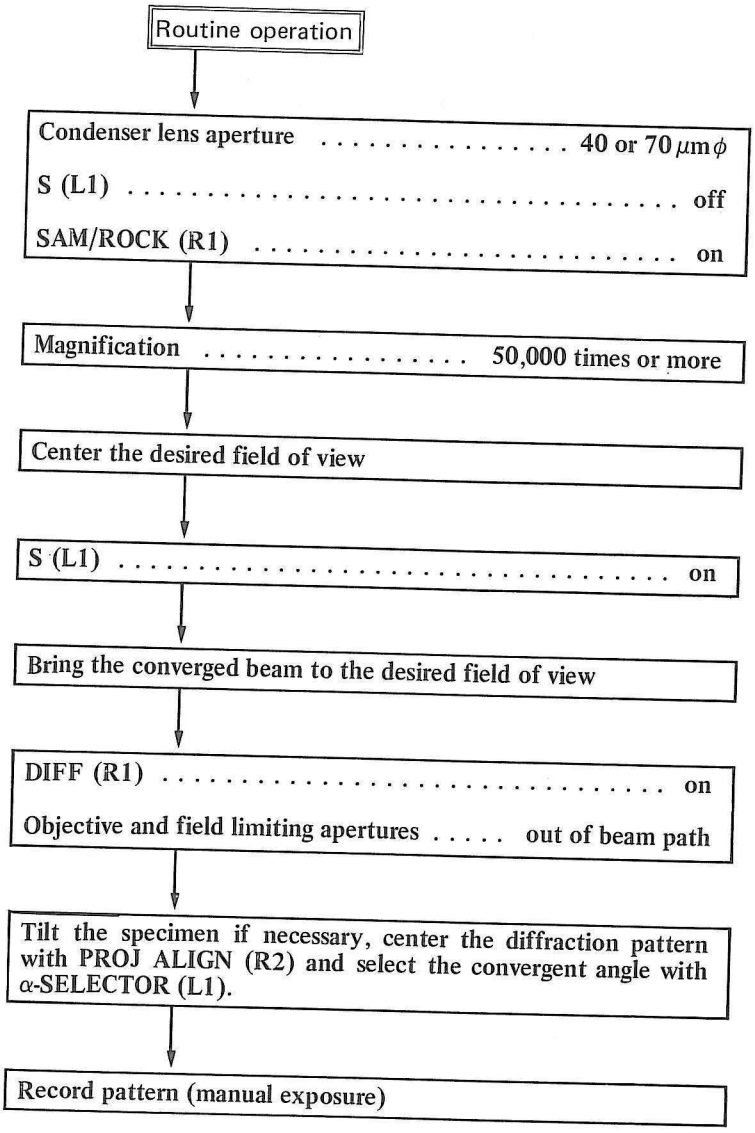
DIFF (R1) ..... Press

DIFF FOCUS (R1) ..... Focus direct spot

Record diffraction pattern by manual exposure

Convergent beam electron diffraction

(Sect. 5.7.4)



Electron gun filament replacement

(Sect. 6.1)

FILAMENT (L1) ..... OFF
HT (L1) ..... Off
GUN AIR (L2) ..... On

↓ Wait until the PIG2 indicates 250μA.

LIFT (L2) ..... On

↓

Anode chamber ..... Cover

↓ Wait for Wehnelt to cool

Electron gun ..... Check grounding

↓

Cylinder ..... Remove

↓

Wehnelt ..... Disassemble

↓

Wehnelt ..... Clean (Sect. 6.7)

↓

Filament ..... Replace
Wehnelt ..... Assemble

↓

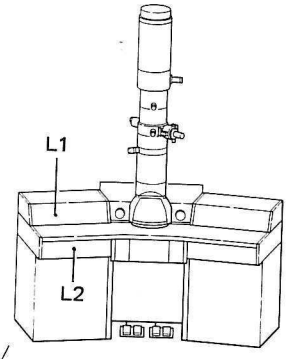
Wehnelt cap ..... Adjust (0.65 mm)

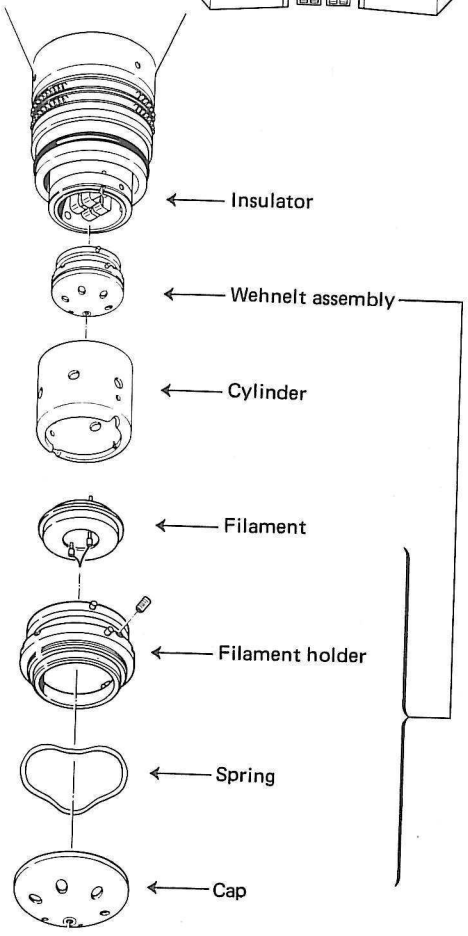
↓

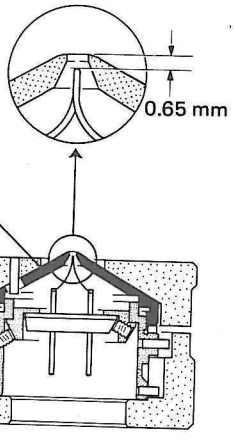
Wehnelt, cylinder ..... Replace

↓

GUN AIR (L2) ..... Off







Baking out the column

(Sect. 6.5.1)

Accelerating voltage reading ..... Max. 120kV

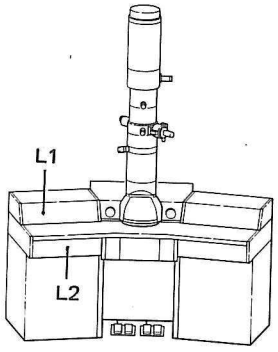
FILAMENT (L1) ..... Off

HT (L1) ..... Off

LENS POWER SUPPLY (L2) ..... On

BAKE OUT (L2) ..... On

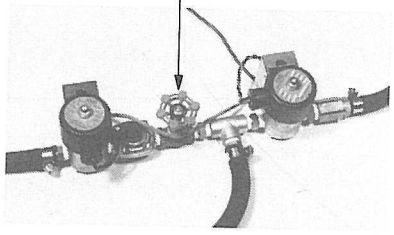
Lens cooling water manual valve ..... Close



Leave for 10 hours

LENS POWER SUPPLY (L2) ..... Off

BAKE OUT (L2) ..... Off



Leave for 3 hours

Lens cooling water manual valve ..... Open fully

LENS POWER SUPPLY (L2) ..... On