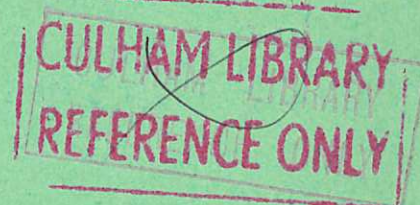
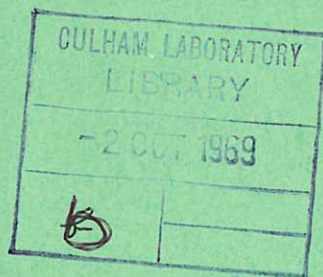


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A FOCUSING X-RAY SPECTROGRAPH FOR USE IN THE RANGE $0.5 \text{ \AA} - 50 \text{ \AA}$

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1969

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by

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A B S T R A C T

A 5-metre curved grating instrument is described that will record diffracted spectra photographically to a short wavelength limit below 1 Å. A 295 lines per mm NPL X-ray reflection grating is used at grazing angles of incidence of 10, 20 and 40 arc minutes. Spectra have been recorded from an X-ray tube and from the Plasma Focus at the Culham Laboratory. The 17" long instrument is capable of resolving the copper $K\alpha_1\alpha_2$ doublet at 1.540 Å and 1.544 Å in the fourth order.

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1. INTRODUCTION

The steady increase in the energy-density achieved in laboratory plasmas in recent years has led to devices with densities of 10^{19} particles per cc that emit thermal X-radiation which peaks at a wavelength $\lambda \approx 2 \text{ \AA}$. The pulsed 'Plasma Focus' device at the U.K.A.E.A. Culham Laboratory is in this class and directly stimulated the design objectives of recovering spectra from two decades of wavelength, $0.5 \text{ \AA} - 50 \text{ \AA}$, from one pulsed event. (Long et al. (1967)). A well-proven grazing incidence instrument (Gabriel et al (1965)) has been used successfully on the device in the range $7 \text{ \AA} - 950 \text{ \AA}$ (Peacock et al. (1969)). The short wavelength performance however is limited by the grating radius, minimum value of the angle of incidence and the grating design.

Historically the diffraction of X-rays below 4 \AA by plane ruled gratings may be traced back to Compton and Doan (1925) who successfully evaluated absolute wavelengths for the characteristic radiation of Mo at 0.7 \AA . In 1929 J.A. Bearden used 50 and 600 ℓ/mm plane gratings in a 270 cm long instrument to determine accurate values for the Cu K lines at 1.4 \AA and 1.5 \AA . Spectra of superb quality were recorded in orders up to $n=12$. Resolution, however, was limited by the plane nature of the grating and by the beam collimation. The prime motivation for these classic studies was the determination of the absolute wavelengths of the X-ray lines. More recently, renewed interest has been stimulated in the techniques of X-ray grating production (Sayce and Franks (1964), Stanley et al. (1968), Franks and Lindsey (1968)) by the possibility of applications in such fields as electron probe microanalysis and high temperature plasma physics, where, for example, the data recording time may be at a premium. The extension of these

techniques to curved gratings, of necessarily high radius of curvature, permits a simultaneous focus over a wide range of wavelengths, compared to the essentially monochromatic nature of Bragg crystal spectroscopy. This wide wavelength coverage can be of sufficient advantage to offset the difficulties of metrology and alignment that are intrinsic to extreme grazing incidence Rowland circle mountings.

2. DESIGN

The instrument described in this paper uses a curved grating of 5 metres radius and operates at a minimum grazing angle of incidence of 10 arc minutes to guarantee that the incident radiation is totally externally reflected from the grating at the short wavelength end of the usable range, set nominally at 1 \AA . This requirement imposes severe restraints on the nominal Rowland circle diameter and grating size, and essentially controls the whole design.

The small angles of grazing incidence dictate the extremely precise mechanical tolerances which must be achieved, coupled to a high degree of mechanical reproducibility and stability between component interfaces. The Rowland circle is thus chosen as the mechanical datum and is a 2500.0 mm radius convex arc machined as the top surface of a 17" x 5" x 3" channel section casting in 'Electron' Mg/Zr alloy type ZRE 1. The 2500.0 mm radius has a tolerance of 0.25 mm with a true arc form variation of 0.005 mm.

The front and lower surfaces of this block are also accurately machined as secondary orthogonal references for the location of the grating pole. A 12" film plate (Ilford Q2) is directly referenced to this curve, while the main slit and grating are rendered coplanar with it by an intermediate assembly registered against the curve by

four precision ground rollers. The entire instrument weight is 7.5 kg. A general view of the instrument is shown in figure 1.

3. GRATING ASSEMBLY

The grating assembly is shown schematically in figure 2. It consists of a rigid plate P supported by four rollers D on the Rowland circle curve A. The upper and lower surfaces of this plate are lapped parallel to 20 arc seconds over its 12 cm length. The effect of the relative diameters and the spacing between the pairs of rollers displaced along the Rowland curve is such that the plate P provides a datum that is parallel to the entrance axis of the instrument. The entrance slit assembly K is supported from the upper surface of the plate P. The grating B is carried on the carriage assembly G which is constrained to rotate about the axis of the rollers adjacent to the grating. Flat datum surfaces are provided on the grating blank to facilitate accurate location of the grating relative to the slit assembly and Rowland circle. The principal grating reference surface is in the tangent plane and is a circumferential witness C around the concave ruled area, engaging, under light spring pressure, with a plane lapped surface tangent to the Rowland circle at the pole. This latter surface, which carries the grating, is machined into the end of a hollow support tube N, sliding in V ways in the carriage G. This arrangement allows both a radial movement of the grating (focus) and a rotation about the support tube axis.

4. ADJUSTMENTS

The adjustments are shown in figure 2 as follows:

- (a) Grating Rotation - A lever arm J rotates the grating support tube N to render the rulings parallel to the Rowland cylinder. This

adjustment is made by metrology from the grating blank reference datum.

(b) Tangency and Grazing Angle of Incidence - Adjustment of micrometer H rotates the carriage G and hence the grating B about its pole. This adjustment, arranged to give one arc minute per division (0.001"), is either used in conjunction with (c) below, to bring the instrument into an optimum focus, or to change the angle of grazing incidence. The slit jaws do not require re-setting for this latter operation but the diameter of the front pair of rollers D must be changed to an appropriate new value and the slit assembly K must be relocated at L.

(c) Focus - The grating support tube N moves in the V-ways of the carriage G to give the radial focus adjustment. The reducing lever F gives a 3.7 micron radial movement for one scale division (0.001") of the micrometer E. A quick action override adjustment, not shown in figure 2, lifts the grating in its support housing by 3 mm for observation of the direct beam.

(d) Zero Order Suppression - A zero order occulting blade of tungsten is provided to reduce background light levels at the short wavelength end of the plate. This blade is adjusted through the micrometer M.

5. SLITS

The 1 mm thick tungsten primary slit K is situated 14 mm from the grating pole for a 10 arc minute angle of grazing incidence and its depth from the tangent plane at the grating pole is 48 microns. For good X-ray definition the lapped edges of the jaw blades have a flat contact area approximately 0.004" in thickness preceded by a 5° taper. Each jaw in turn is lapped into the jaw housing to ensure a coplanar reference. The material of the jaw housing is chosen to match the expansion coefficient of the slits. With the slit K in its

10 arc minute position two foreslits may be placed at L to attenuate the debris from plasma sources and limit the incident beam acceptance angle to the instrument aperture (0.002 radian). It has been found useful to check the operational angle of incidence by removing these foreslits and measuring the fringe separation in a Lloyd's mirror experiment. An intense monochromatic source, in the present case the Na-D lines, is needed in such an arrangement to illuminate the primary slit.

6. VACUUM CHAMBER

Figure 4 shows the instrument housed in its aluminium vacuum tank for use above the air cut-off at 4 Å. A spring load registers the instrument against a 'V, cone and plane' kinematic location. This location is independent of the direction of gravity and is shown as A in figure 4. The arrangement for vertical and horizontal use is also indicated. An externally operated shutter is provided at B.

7. REGISTRATION

Because of the extremely small grazing angles a very thin, yet precisely defined, film surface must be employed. The instrument is thus designed to take a 12" x 2" Ilford Q2 plate 'extra thin' grade. Figure 3 shows the instrument in cross-section at an arbitrary position along the focal curve. The plate A is constrained against the focal curve by two silicon rubber cords E, housed in the backing plate B. An adjustable back-stop is provided at the extreme long wavelength end of B to render the short-wavelength end of the plate coincident with the zero order image.

8. PERFORMANCE

Figure 5 shows the results of approximate calculations for resolving power $\lambda/\Delta\lambda$ plotted as a function of wavelength. Curve A is for detection in a plane of zero thickness using an 'optimum' value of slit width (Mack et al. (1932)). In practice the combined effect of Q2 film thickness, X-ray penetration and a slit width \approx 1 micron reduce the resolution to the values indicated by curve B. The values indicated by triangles are based upon measured instrumental line widths following a focusing trial with the proto-type instrument. By comparison curve C shows the resolution required to identify unambiguously K radiation from adjacent elements in the range bromine to magnesium.

The spectrum shown in figure 6 was taken with the spectrograph operated in air using a Philips PW 1009 X-ray tube. It is reproduced in three ranges of contrast as there is an over-exposure of $\times 400$ in first order $\text{CuK}\alpha$ compared to the exposure required for a plate density of 0.5. This over-exposure is accepted in order to exhibit the fainter features throughout the range.

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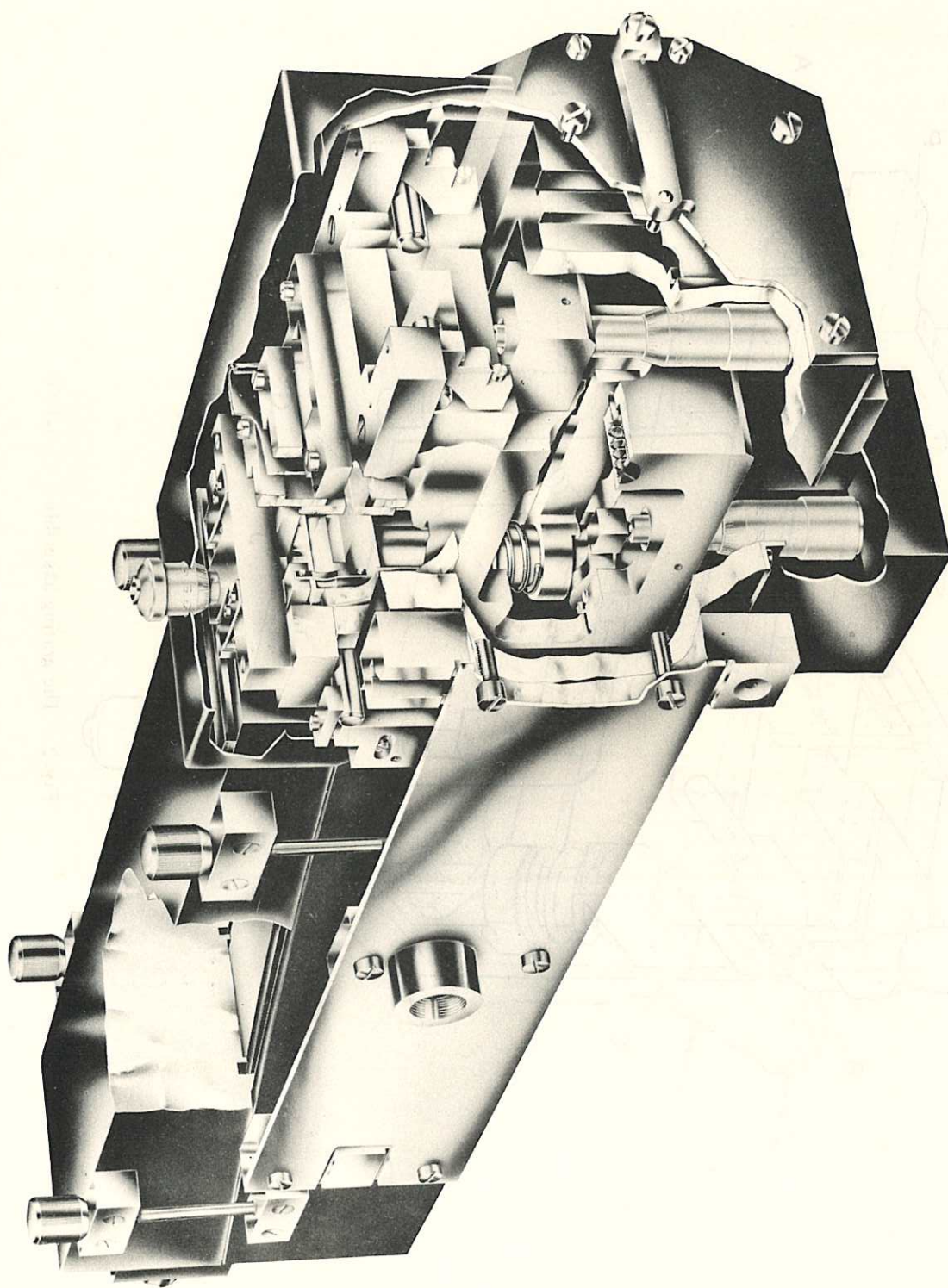


Fig. 1 X-ray grating spectrograph (CLM-P 207)

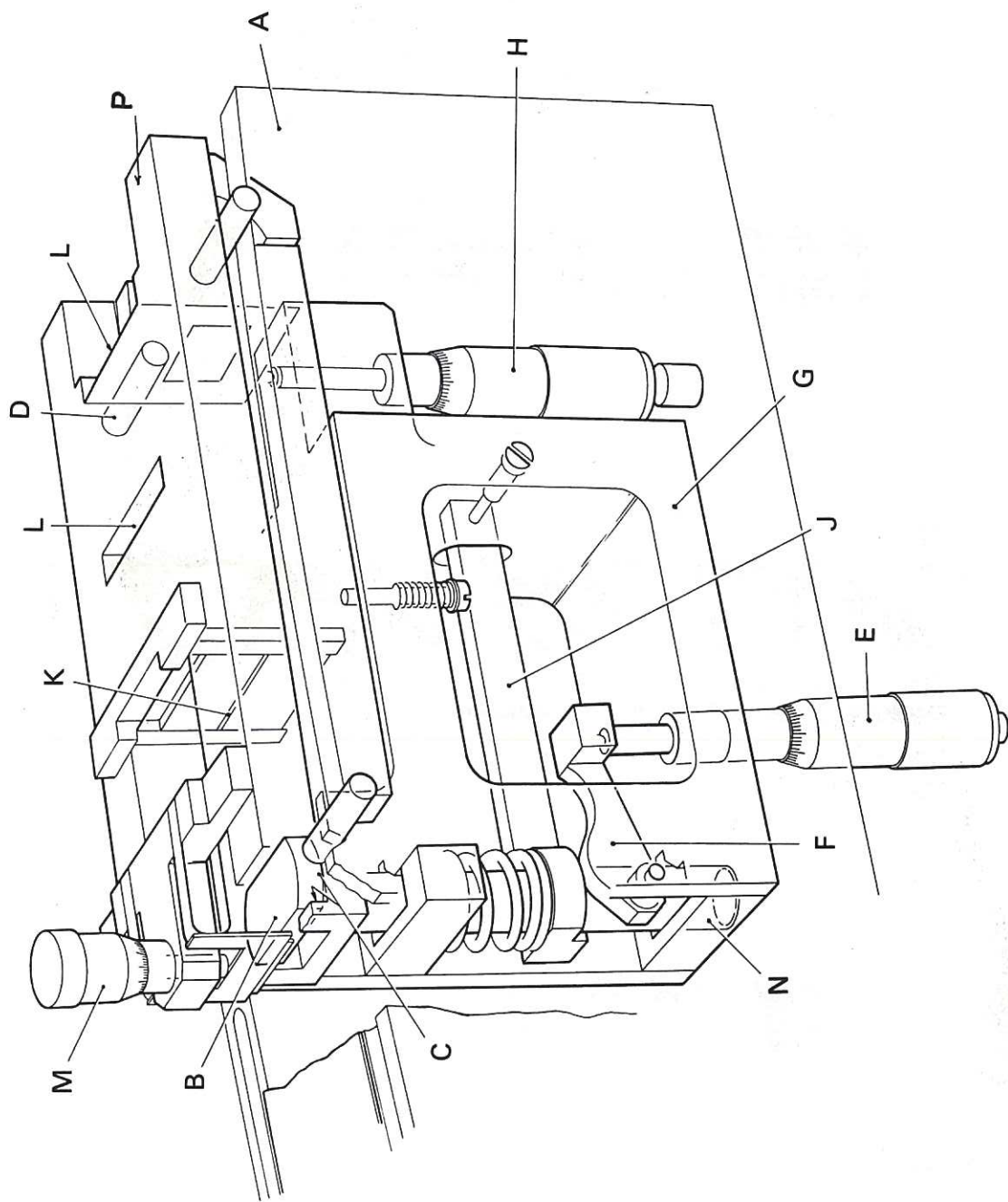


Fig.2 The grating assembly (CLM-P207)

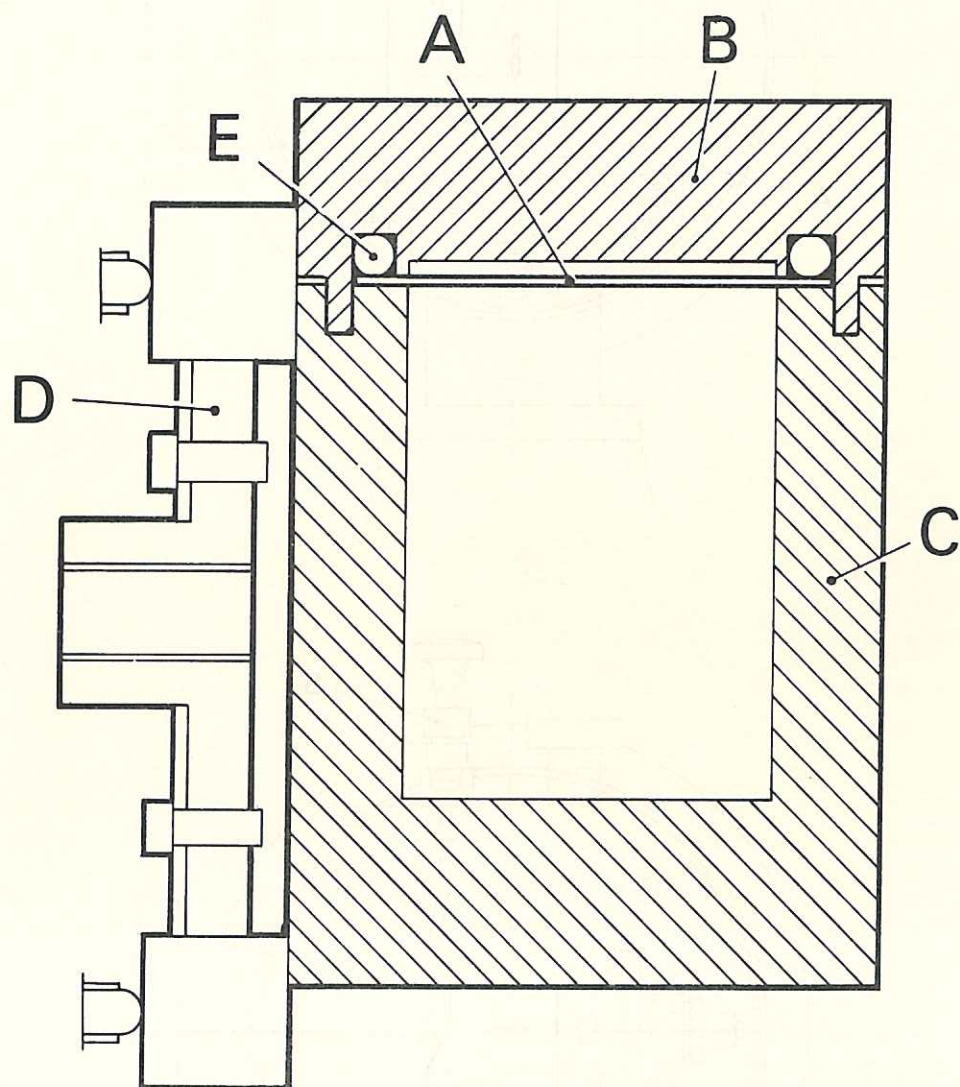


Fig. 3 Plate cassette cross section (CLM-P 207)

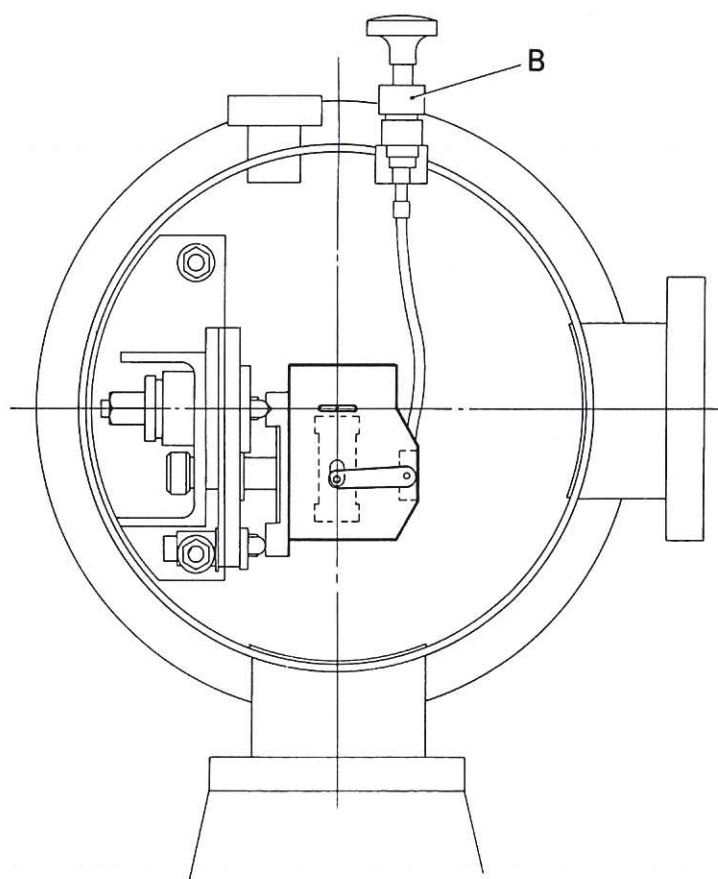
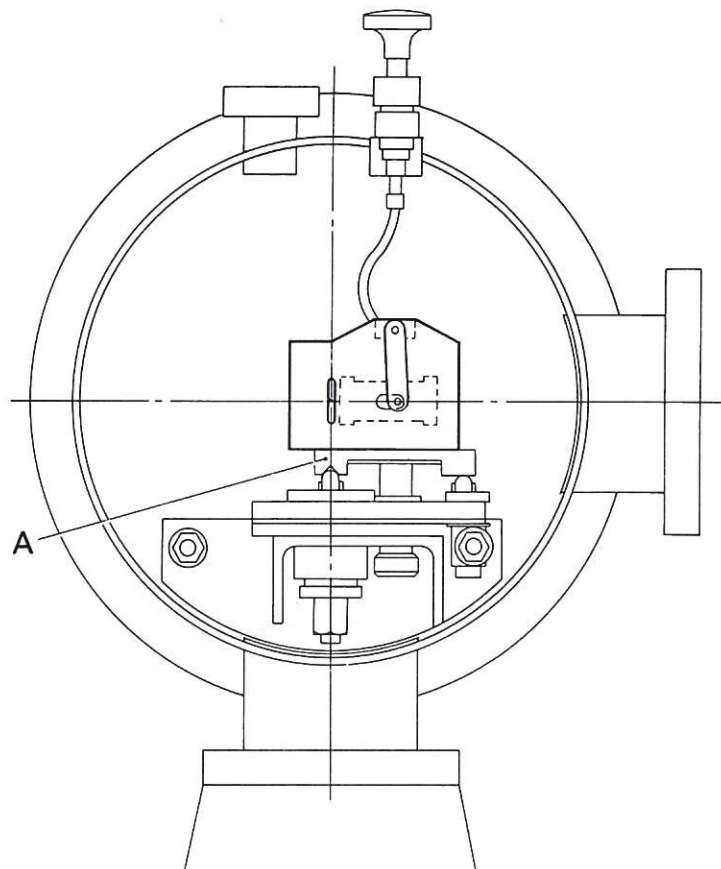


Fig.4 Spectrograph vacuum chamber and mountings (CLM-P 207)

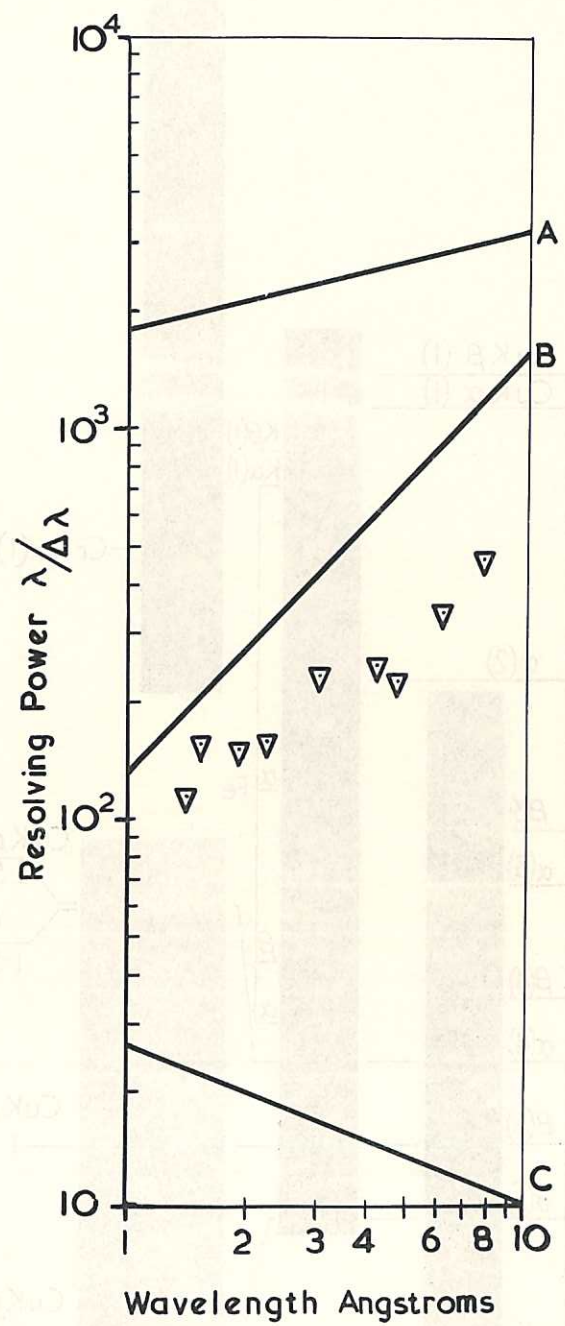


Fig. 5. Spectrograph resolving power (CLM-P 207)

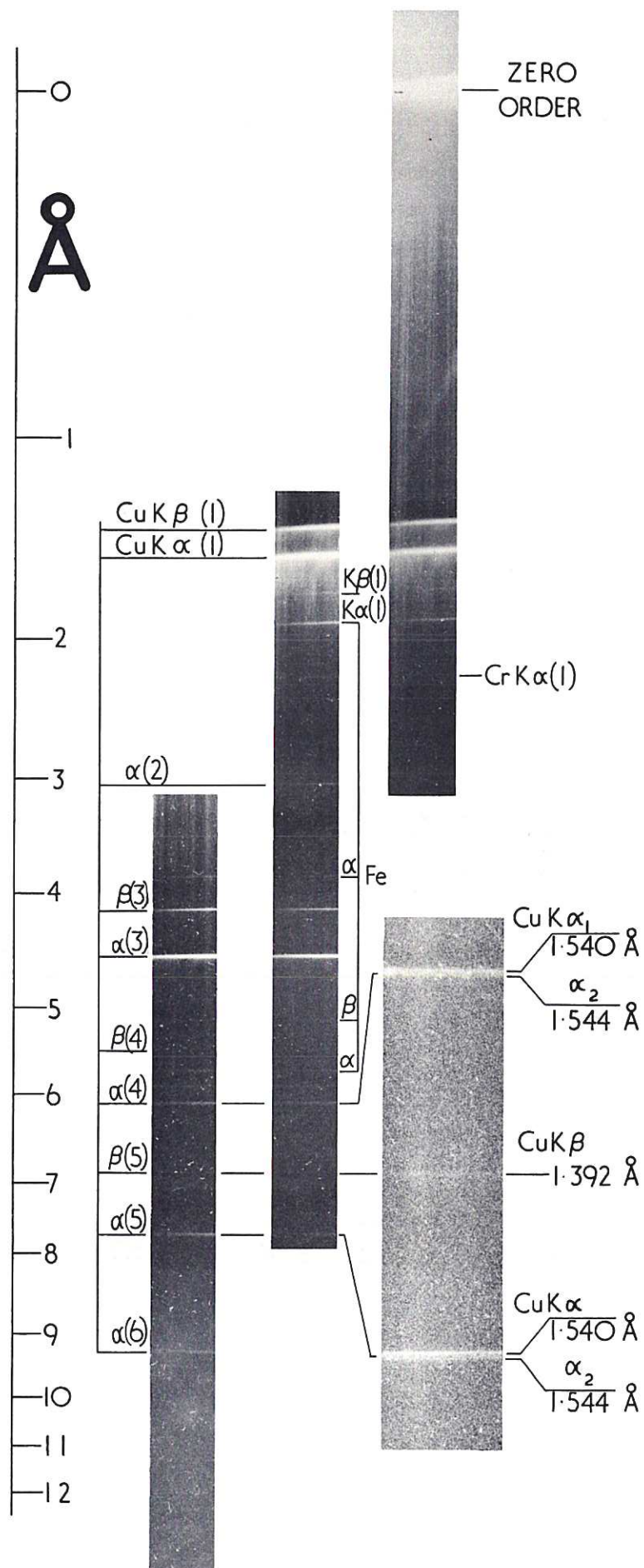


Fig. 6 (CLM-P 207)
X-ray spectrum showing resolution of Cu K $\alpha_1\alpha_2$ in 4th and 5th order

