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Preprint

SPECTROGRAPH CALIBRATION AT SOFT X-RAY WAVELENGTHS

I - From Grating Diffraction Efficiency and Plate Response Factors.

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SPECTROGRAPH CALIBRATION AT SOFT X-RAY WAVELENGTHS

I - From Grating Diffraction Efficiency and Plate Response Factors

by

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ABSTRACT

The sensitivity of a grating spectrograph has been constructed from measurements of the absolute efficiencies of the diffracting element and of the recording emulsion. Results are presented for light at wavelengths between 8 Å and 44 Å incident on a "blazed" grating at an angle of 88^{o}.

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1. INTRODUCTION

The sensitivity of a spectrograph is usually measured from its response to some standard source whose emission over the wavelength range of interest is known. In the soft X-ray region suitable sources are relatively few. However, to cite an example, Morgan, et al., (1968) have used both the continuum emission from a 335 MeV synchrotron and the X-ray K-line emission from electron-bombarded targets to calibrate a grazing-incidence spectrograph over the range 10 Å to 120 Å. The calibration of a similar spectrograph which has the x-radiation incident at a grazing angle of 2^o on a concave, "blazed" grating is the subject of this and the following paper. The approaches reported in these papers differ substantially from on another and are extensions of previously reported calibration techniques, see for example "Conference on Calibration methods in the Ultraviolet and X-ray regions of the Spectrum", ESRO publication, SP-33, (1968).

In this paper use is made of discrete K-lines from various X-ray sources whose emission is absolutely measured by a flow proportional counter as described by Jones and Freeman (1968) and by Morgan et al., (1968).

In the present paper however, the diffraction grating and the photographic recording emulsion are treated as constituent elements in the instrument sensitivity and each element is measured separately. Now that grating calibration has become possible on a routine basis (Speer, 1970) this approach allows the flexibility of changing gratings and recording emulsions. The calibration is reported for wavelengths between 8 and 44 Å since it is in this region that the electron distribution in laser-produced plasmas can be derived directly from the Lyman continuum of completely-stripped light elements such as carbon, Galanti and Peacock (1973).

In the following paper, Irons and Peacock (1973) the sensitivity of the spectrograph is measured as a complete unit with a rather novel calibration source, a laser-produced plasma, which is itself calibrated in the X-ray region after referring to a visible standard using the branching ratio technique. Thus, the calibration method described by Boland et al., (1968b), has been extended to wavelengths below 100 Å.

2. THE INSTRUMENT SENSITIVITY

The type of 2 metre grazing-incidence spectrograph used in this study has been described by Gabriel, et al., (1965) and a calibration procedure for this instrument has been described by Morgan, et al., (1968). In common with the latter publication we define the sensitivity of spectrograph S_λ as a product of the photographic emulsion response P_λ, the diffraction efficiency of the grating G_λ and the width of the entrance slit, W.

$$S_\lambda = P_\lambda \cdot G_\lambda W, \quad \text{density erg}^{-1} \text{ cm}^{-3}.$$

The elements P_λ and G_λ in this expression are also sensitive functions of the angle of incidence but in the present two papers this was kept fixed at 88^o. The grazing angle of 2^o was located by metrology to within a few tenths of a percent.

3. GRATING EFFICIENCY

The Bausch and Lomb diffraction grating employed in this paper, serial number 2278-30-2-6, is similar to that employed in the following paper, Irons and Peacock (1973). The ruling frequency of both gratings is 600 grooves/mm with a blaze angle listed at $1^o 31'$ and both have a gold surface. There are differences between the two gratings which may be significant however. The serial number of the present grating, 2278-30-2-6, shows that it has been replicated from a different sub-submaster and that the replica has had a gold parting layer when separated from its master. That is, the grating is a 'gold replica' rather than 'gold-coated' (i.e. an overcoating, of Au on an Al replica) as used in the paper by Irons and Peacock (1973). A discussion of the relative merits of these types of grating surfaces and of the significance of the blaze angle is given by Loewen et al., (1973).

The absolute efficiency of the grating as a function of angle of incidence and of wavelength was measured on the grating test facility at Imperial College, London University, Speer (1970). The efficiencies of the first diffracted orders at 8.3 Å and 44.5 Å are shown in figure 1 and have been reported previously, Speer (1972). At an angle of incidence of 88° (2° grazing angle) the first order efficiency expressed as a percentage of the total monochromatic energy falling on the grating is 2.25% at 8.3 Å and 7.0% at 44.5 Å . Values at 9.9 Å and 18.3 Å were linearly interpolated at 2.5% and 3.5% respectively. Typical errors on these efficiencies are of the order of $\pm$ 5%.

4. EMULSION RESPONSE

The emulsion sensitivity, or plate response factor, is defined as the density per unit flux of radiation incident normal to the emulsion and is, in fact, the gamma of the emulsion in the range where its response is linear. Absolute characteristic curves for two quite different types of emulsion, Ilford "Q.2", used commonly in the grazing-incidence region and Kodak, "Kodirex" X-ray film, have been determined using the X-ray source of discrete K lines and the flow proportional counter developed by Jones and Freeman (1968), as an absolute source of X-ray photons.

Curves at wavelengths 2.10 Å (MnK_α -Fe^{55}), 8.34 Å (AlK_α), 9.89 Å (MgK_α), 18.3 Å (FK_α) and 44.7 Å (CK_α) were determined with radiation incident normally on both emulsions, and at 9.89 Å and 44.7 Å with radiation incident at a glancing angle of 3^o on "Q2" corresponding to the angle of diffraction experienced in the spectrograph. All films were developed for 4 minutes in Kodak DX 80 at 20^oC, washed in running water, and fixed for 5 minutes in M & B Amfix. Statistical errors in the measurements of the density, D, and of the incident energy are estimated at $\pm$ 5%. Figures 2 and 3 show these experimental curves up to densities of 0.3 for Q2 and Kodirex respectively and indicate that the response is linear for all wavelengths up to densities of 0.2 for Q2 and up to and beyond 0.3 for Kodirex. The plate response factors, P_λ, for Q2 at 8.34 Å, 9.89 Å, 18.3 Å and 44.7 Å are thus 0.955, 1.45, 3.07 and 9.00 density $erg^{-1}cm^2$, respectively, at normal incidence, and 1.51 and 8.33 at grazing incidence for 9.89 Å and 44.7 Å. Probable errors of P_λ are of the order of $\pm$ 10% in each case.

Figure 4 shows the H (i.e. log E) and D curves for both emulsions extending well above their linear range and up to D = 1.8. The wavelength variation in the response of these two emulsions is markedly different: this difference and the angle of incidence dependence are ascribed to the finite thickness of the sensitive layer and to reflection at the surface of the emulsion.

Light penetration ($^1/e^{th}$ transmission) into X-ray emulsions, such as Kodirex which has a 15 μm thick gelatin supercoat, varies from 25 μm for 2.1 Å radiation through 3.4 μm for 8.3 Å and 1.2 μm for 12 Å radiation, Atkinson and Pounds (1964)). This explains the decreasing response with wavelength and is normal for X-ray emulsions.

In contrast, the response of the Q-2 emulsion increases with wavelength on this range and is particularly sensitive between 2 Å and 8 Å. The active layer in Q-2 emulsion, however, is confined principally to the upper regions of the 4 μm thick coating and a typical value for its thickness would be of the order of 1 μm. The increasing fraction of the softer radiation stopped in this thin active layer explains the Q2 response characteristics. A longer path length in the emulsion also accounts for the slight improvement in sensitivity for 9.89 Å radiation at glancing incidence over that at normal incidence, figure 2.

At 44.7 Å all the radiation would be absorbed in the Q-2 active layer at normal incidence and no improvement in sensitivity would be expected on varying the angle of incidence. Indeed a fall in sensitivity would be expected at small glancing angles due to the increase in reflectivity of the emulsion. The critical angle for total reflection, θ_c, from typical emulsions at 44.7 Å is in the order of 4^o to 5^o. Allowing for the fact that the transition to full total reflection occurs over several degrees below θ_c at such wavelengths, Dershem and Schein (1931), then at a glancing angle of 3^o, a reflection of 8% is not an unreasonable figure to deduce from the observed reduction in sensitivity between normal and grazing incidence for 44.7 Å and at a density of 0.1, (figure 2).

The overall agreement shown in figure 5 between the sensitivity of the spectrograph derived using these emulsion characteristics and from the techniques described in the following paper, Irons and Peacock (1973), is a good indication that reciprocity failure is not an important factor over this wavelength range.

5. OVERALL SENSITIVITY CURVE

For a slit width of 10 μm and Q-2 emulsion, a sensitivity curve for this instrument, shown in figure 5, has been constructed from the separate measurements of P_λ and G_λ. Typical errors, of the order of ± 15%, are indicated. Also indicated are the sensitivities obtained by calibrating the instrument as a whole from a soft X-ray source and by the branching ratio technique, Irons and Peacock (1973). The dashed curve is due to Morgan, Gabriel and Barton (1968) and refers to a similar instrument but with a platinum coated grating. The results from all these sources are remarkably consistent, and agree within the experimental errors quoted. From this evidence there is little to choose between a gold or a platinum surfaced grating in this wavelength region.

More definite comments on the relative merits of different coatings can be expected from the work of Loewen et al., (1973).

It is generally recognised (Atkinson and Pounds, 1964) that the emulsion loses sensitivity with age and that there may be quite large differences, say up to 40%, between the sensitivities of different batches of experimental film. A more typical figure to cover the range of sensitivity experienced with standard commercial emulsions as used here, would be ± 10%. In addition, the diffraction efficiency of the grating can vary over the area of the ruled surface. In the following paper when using the branching-ratio technique Irons and Peacock (1973), the whole aperture of the grating is illuminated, while with the X-ray line sources in both papers just over half the central area of the grating was measured. The general agreement, shown in figure 5, between the results using these different techniques suggests that systematic errors due to the two factors mentioned above are not more than the overall statistical errors in the measurements, which itself corresponds to a probable error in the calibration of 20%.

CONCLUSION

A sensitivity curve has been constructed for a 2 metre grazing incidence grating spectrograph from the individual sensitivities of its components, grating and emulsion. This is deemed a more flexible approach than calibrating the instrument as a whole unit and allows the free interchange of gratings and recording emulsions. Sensitivities compare well with those obtained by the branching ratio technique for the same instrument and for a similar instrument with a grating of different coating material.

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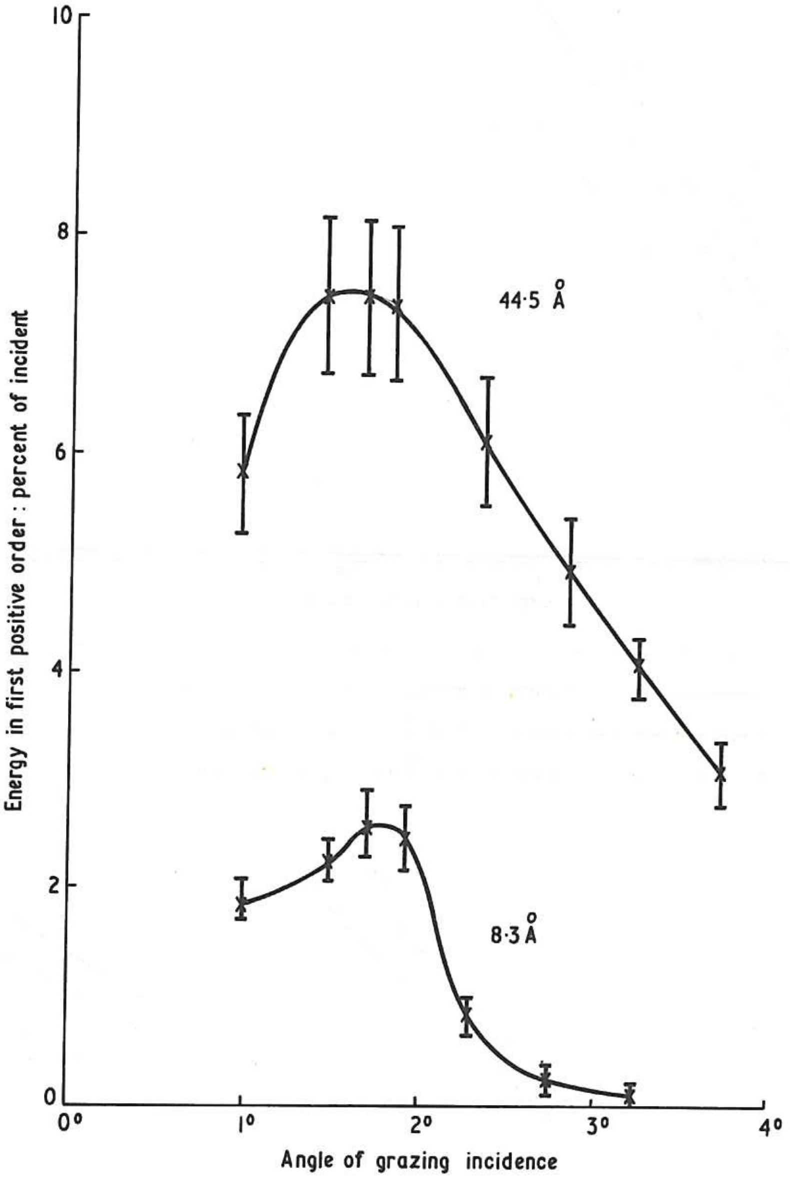

Fig. 1 First order Diffractions Efficiency of Gold replica, concave grating Bausch and Lomb, 2278-30-2-6.

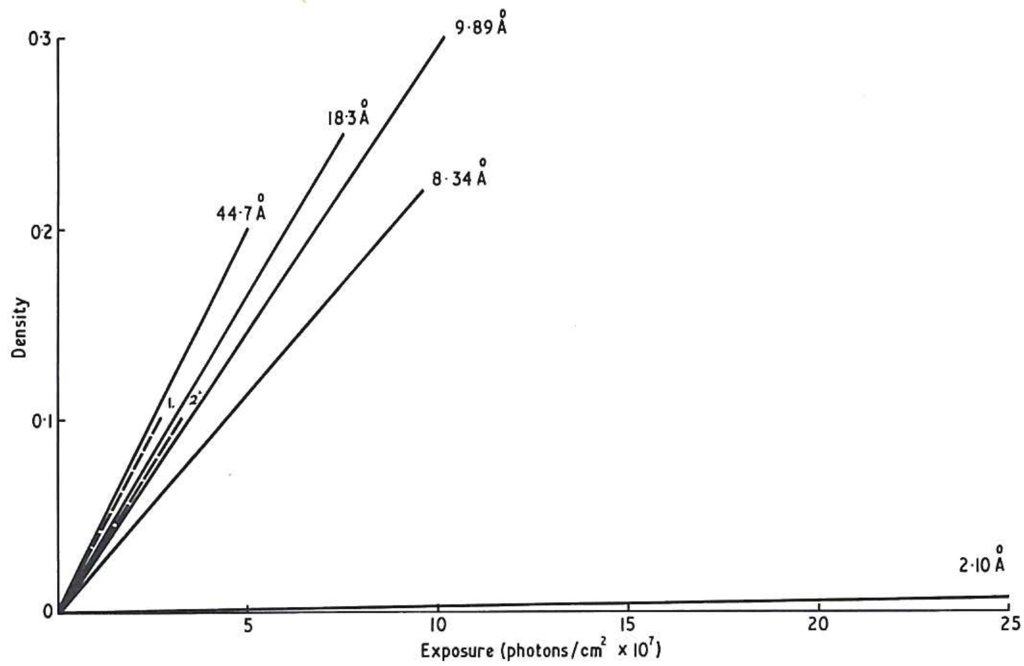

Fig. 2 Characteristic Curves of Ilford Q-2 Emulsion (Developed in Kodak DX80).

———————— refers to normal incidence

1 – – – – – – – – refers to 44.7 Å at grazing incidence

2 – – – – – – – – refers to 9.89 Å at grazing incidence

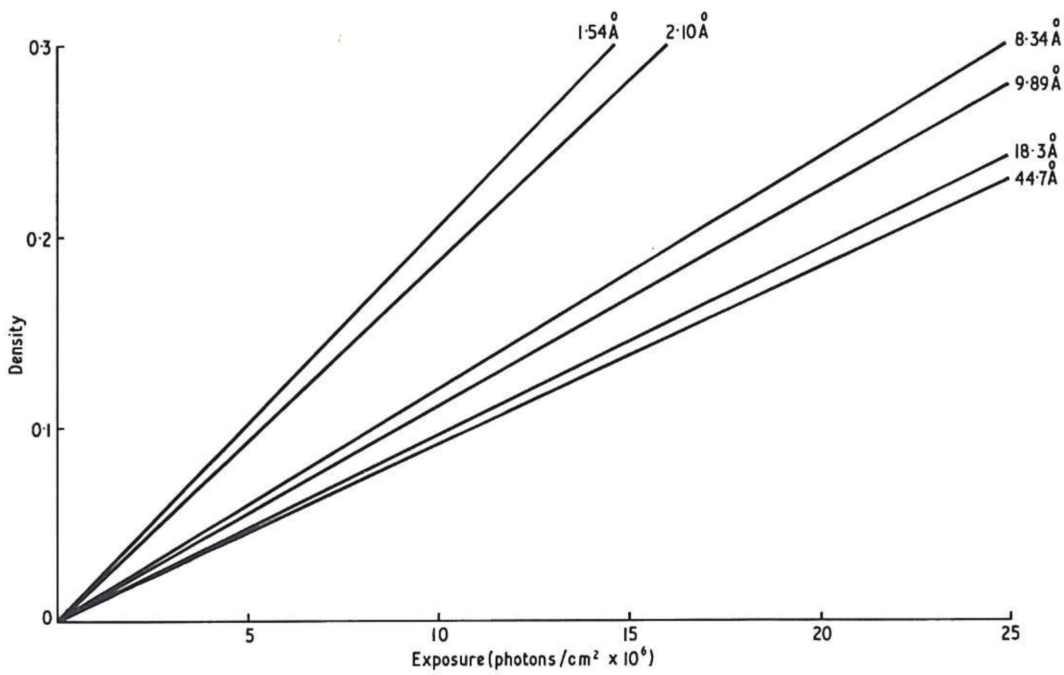

Fig. 3 Characteristic Curves of Kodak Kodirex Emulsion at Normal Incidence (Developed in Kodak DX80).

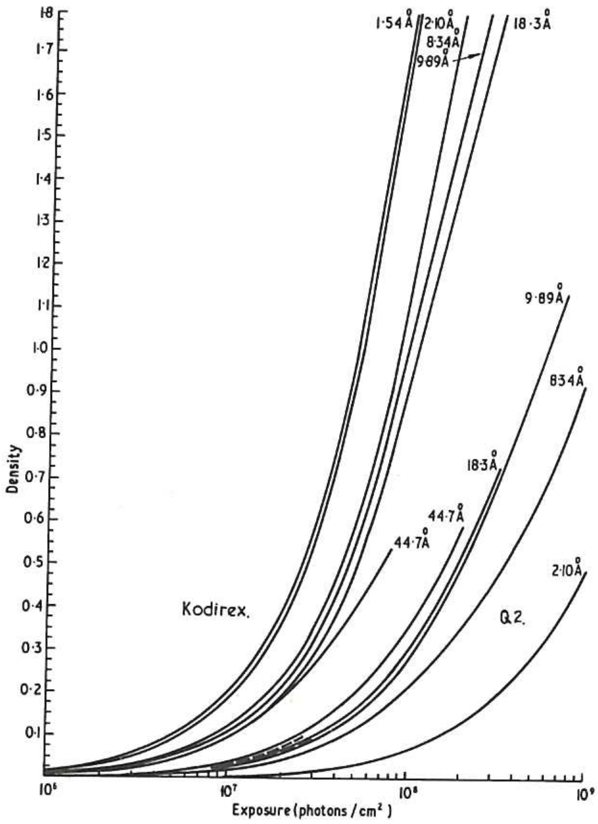

Fig. 4 Characteristic Curves of Ilford Q-2 and Kodak Kodirex Emulsions Developed in Kodak DX80.

- - - - - - refers to grazing incidence.

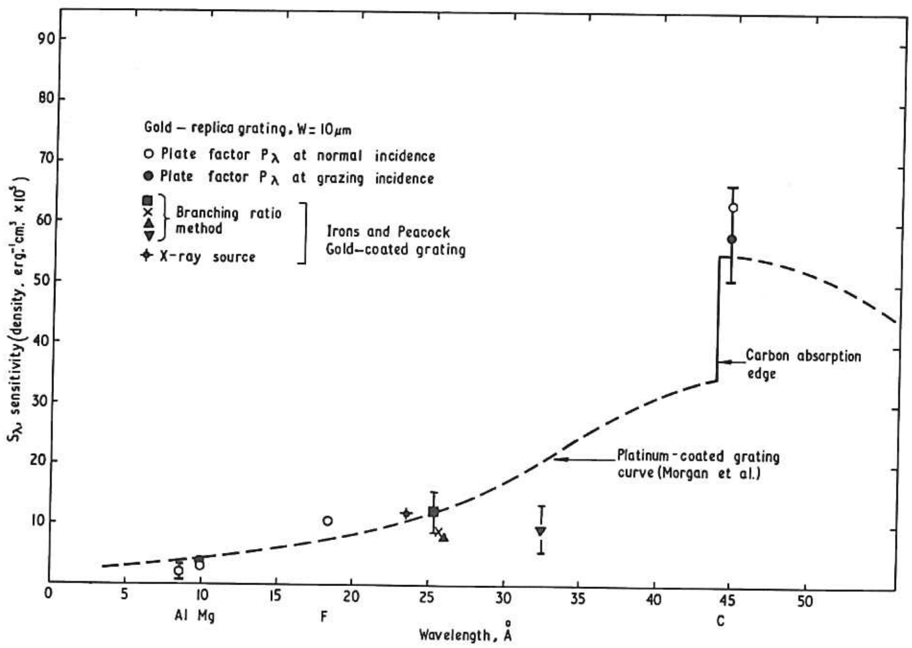

Fig. 5 Grating Spectrograph Sensitivity Curve.

- - - - - - refers to Morgan et al., (1968)

○ present results P_λ at normal incidence

● " " P_λ at grazing incidence

The other experimental points are taken from Irons and Peacock (1973).