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INTERNAL-GRATING ELECTRONOGRAPHIC SPECTROGRAPHS FOR THE FAR ULT--ETC(U)
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# INTERNAL-GRATING ELECTRONOGRAPHIC SPECTROGRAPHS FOR THE FAR ULTRAVIOLET AND X-RAY WAVELENGTH RANGES



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## ABSTRACT

Described are concave-grating spectrographs, of the normal-incidence and grazing-incidence types, using electronographic recording with a front-surface alkali-halide photocathode on the Rowland circle. The normal-incidence version uses magnetic focusing, with unity magnification, and is useful at wavelengths above 300-400 A. The grazing-incidence version is being developed in two types; one uses magnetic focusing and near-unity magnification, and is intended for applications where high resolution is required but the available flux is relatively high; the other uses electrostatic focusing and a large demagnification ratio and is intended for applications where resolution can be sacrificed to obtain higher sensitivity for weak sources (such as celestial X-ray sources). The use of grazing incidence results in a higher quantum yield from the photocathode, as well as a higher reflectance from the grating, in the extreme ultraviolet and soft X-ray wavelength ranges.

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Introduction

The instruments described here represent an extension of the internal-optic concept[1,2] to include the case where the optical system consists of a single concave grating. Such a configuration is of interest for the following reasons:

(1.) The previously-described electronographic Schmidt and all-reflecting cameras are obviously limited in size, due to the external location (and correspondingly increasing size and weight) of the focusing magnet. Limitations are also encountered in the available sizes of objective gratings and of ultraviolet transmitting blanks for Schmidt correctors. Therefore, for large effective apertures, one must consider an instrument which can be placed at the focus of a large telescope.

(2.) For many types of observations, such as of diffuse sources (comets, galactic nebulae, etc.), it is desirable or necessary to use a slit-type spectrograph rather than an objective-grating type.

(3.) For wavelengths below 1000 A, the reflectances of known mirror coatings are very low, and hence it is necessary to keep the total number of reflections in the optical system to an absolute minimum. Also, no transmissive materials (other than thin metal films) are available in this wavelength range. Therefore, the use of refractive elements (such as Schmidt correctors) is not possible, and any photoemissive surfaces must generally be of the front-surface variety.

**Normal Incidence Spectrograph**

Figure 1 is a diagram of a normal-incidence electronographic spectrograph we are presently developing which uses a concave grating internal to the device, with the entrance slit and front-surface photocathode on the Rowland circle. The plane of the grating and Rowland circle is tilted relative to the axis of the imaging device, so that the emitted photoelectrons can be accelerated along the tube axis and pass over the grating, then being recorded on electronographic film. Figure 2 is a photograph of the present laboratory "breadboard" unit, which uses a solenoid coil to provide the focusing magnetic field, and is equipped with a 40 cm radius, 1200 line/mm grating. This instrument should be capable of better than 0.1 A resolution. With platinum coating on the grating, it is useful at wavelengths as short as 400 A, with some sensitivity perhaps down to 300 A. It could be used at the focus of a large space telescope for studies of celestial objects, or without any additional optics for spectrography of extended, diffuse sources such as the terrestrial airglow and aurorae. In the latter case, the field of view is the projection of the grating through the slit onto the sky- here, roughly an area $4.3^{\circ}$ by $5.4^{\circ}$. The effective focal ratio of this system is about f/10.5.

## Grazing Incidence Spectrographs

For wavelengths below 300 A (and for best efficiency below about 400 A), it is necessary to use the concave grating at grazing incidence. Figure 3 shows the variation of the reflectance of gold vs. angle of incidence for three wavelengths of soft X-ray radiation[3]. This behavior is typical of the other heavy metals which are used as reflecting coatings on mirrors and gratings in this wavelength range.

It is also found that the quantum yields of photoemissive surfaces are improved at these shorter wavelengths by the use of large angles of incidence. Lukirskii and co-workers[4,5] have measured the quantum yields of several photoemissive substances in the soft X-ray wavelength range from about 1.3 A to 300 A. It was found that the quantum yields for a given wavelength of radiation increased as the secant of the angle of incidence, up to an angle (dependent on the wavelength and the photoemissive material) beyond which the quantum yield dropped off sharply with increasing angle (due to increasing reflection from the photocathode). This maximum occurred at larger angles for shorter wavelengths, and (generally, at a given wavelength) for less dense materials (see Figure 4). Heroux et al.[6] found that the variation of quantum yield (for a tungsten photocathode) with angle of incidence, between $0^{\circ}$ and $60^{\circ}$, showed a gradual change from being nearly independent of angle at 1216 A, to closely matching the secant law at 304 A (see Figure 5).

Since, at the shorter wavelengths, the quantum yield depends on the angle of incidence as well as the wavelength, one must determine the angle of incidence for each wavelength of interest.

For a front-surface photocathode on the Rowland circle, the angle of incidence is equal to the angle of diffraction, $\beta$, of the concave grating. This is given by the grating equation

$$n\lambda = d\ (\sin \alpha - \sin \beta)$$

where n is the order of diffraction and d is the grating line spacing (in angstroms). The angle of incidence on the grating, $\alpha$, is determined by the shortest wavelength of interest.

When used at the optimum angle of incidence for each wavelength, the quantum yields of the alkali-halide photosurfaces are found to be very high throughout the extreme ultraviolet and soft X-ray wavelength ranges. Figure 6 shows measurements by Duckett and Metzger[7,8] at normal incidence, and by Lukirskii et al.[4,5] at 67°-70° angle of incidence, for CsI. Judging from the curve for tungsten at 304 A (Figure 5) of Heroux et al., it may be that the apparent discrepancy between the CsI measurements at 300 A and at 500 A may be due to the onset of grazing incidence reflection at 300 A for a 70° angle of incidence. Likewise, at the shortest wavelengths in Figure 6, the quantum yields would be considerably larger if a larger angle of incidence were used.

Figure 7 is a diagram of a grazing-incidence electronographic spectrograph using electrostatic focusing. The present laboratory test unit is based on the electrode structure of a scrap WL-23100 image tube obtained from Westinghouse. This tube was originally used for X-ray imaging, but with an X-ray phosphor/semitransparent visible-sensitive photocathode converter. The front glass window of the tube was cut off, and this conversion screen was removed; in its place was substituted a front-surface alkali-halide photosurface to be illuminated from behind by the concave grating. The approximately 20 cm radius of the original photocathode surface in this tube is a close match to the Rowland circle of a 40 cm radius concave grating.

This image tube has a large demagnification ratio, and hence provides a gain in sensitivity in proportion to the ratio of the image areas on the photocathode and on the electronographic emulsion. However, the resolution is reduced in the same ratio. In many cases, however, the available photon fluxes are so low that one is willing to trade off resolution for increased sensitivity. Such is the case, for example, in the study of celestial X-ray sources. For this application, the instrument would be placed with its entrance slit at the focus of a grazing-incidence telescope, as might possibly be flown on a large orbiting observatory or space station.

Figure 8 is a diagram of a grazing-incidence spectrograph which is magnetically focused and has a demagnification ratio only slightly less than unity ( more precisely, equal to the ratio of the concentric radii of the Rowland circle and of the film holder). Here, the electric and magnetic fields are cylindrically radial, rather than completely uniform. This instrument, which is presently still in the planning stage, would be useful in experiments where resolution, rather than limiting sensitivity, is most important. This would be the case for solar studies and for many laboratory plasma physics investigations.

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6. Heroux, L., Manson, J. E., Hinteregger, H. E., and McMahon, W. J., J. Opt. Soc. Am. 55, 103 (1965)
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8. Metzger, P. H., J. Phys. Chem.Solids 26, 1879 (1965)

FIGURE CAPTIONS

1. Diagram of a normal-incidence concave grating spectrograph with electronographic recording from a front-surface photocathode deposited on the Rowland circle.

2. Photograph of the laboratory test version of the normal-incidence concave-grating electronographic spectrograph.

3. Reflectance of gold vs. angle of incidence for three wavelengths of soft X-radiation[3].

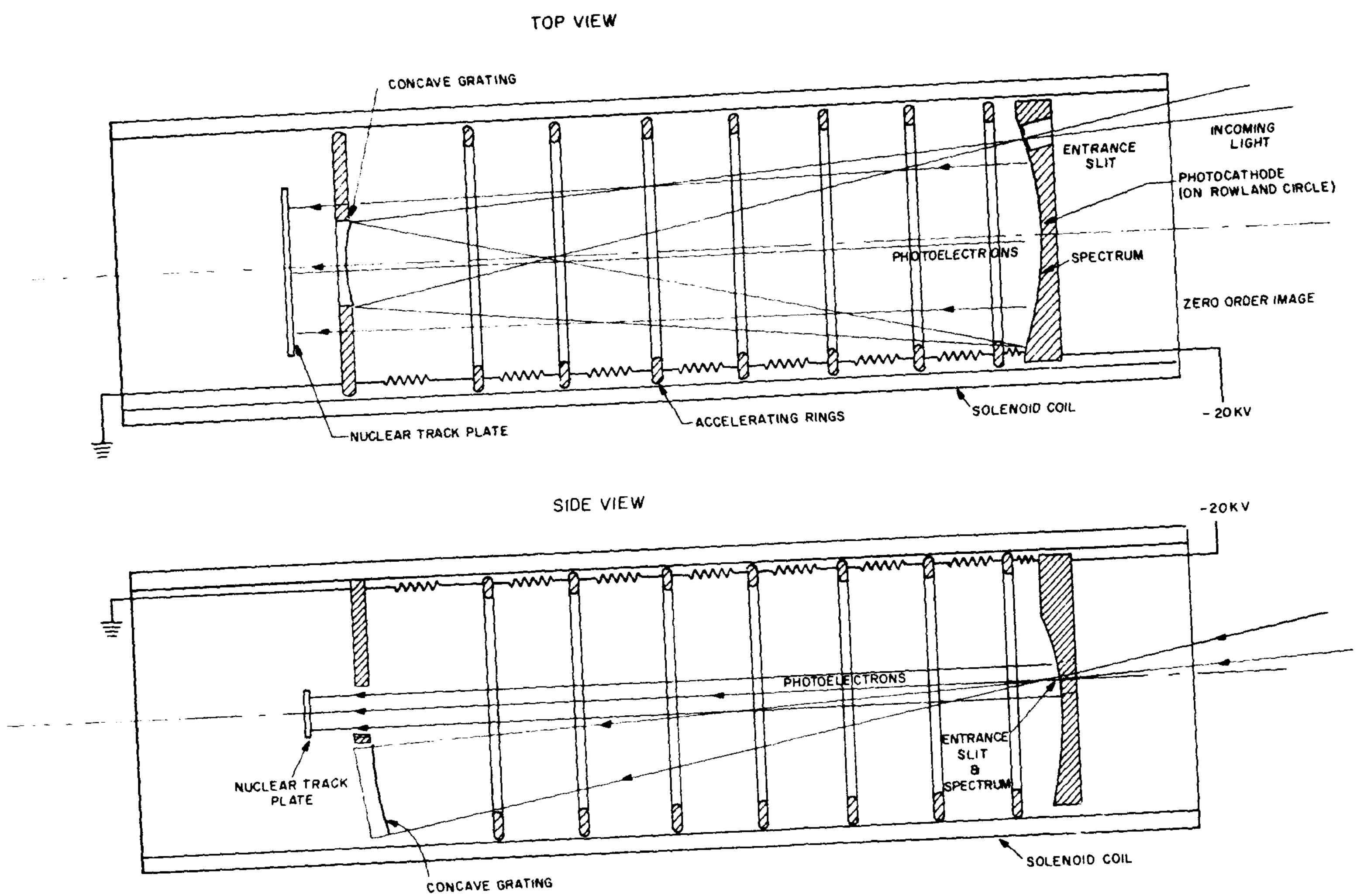
4. Quantum yield of CsI and LiF photocathodes vs. angle of incidence for various wavelengths of soft X-radiation[4].

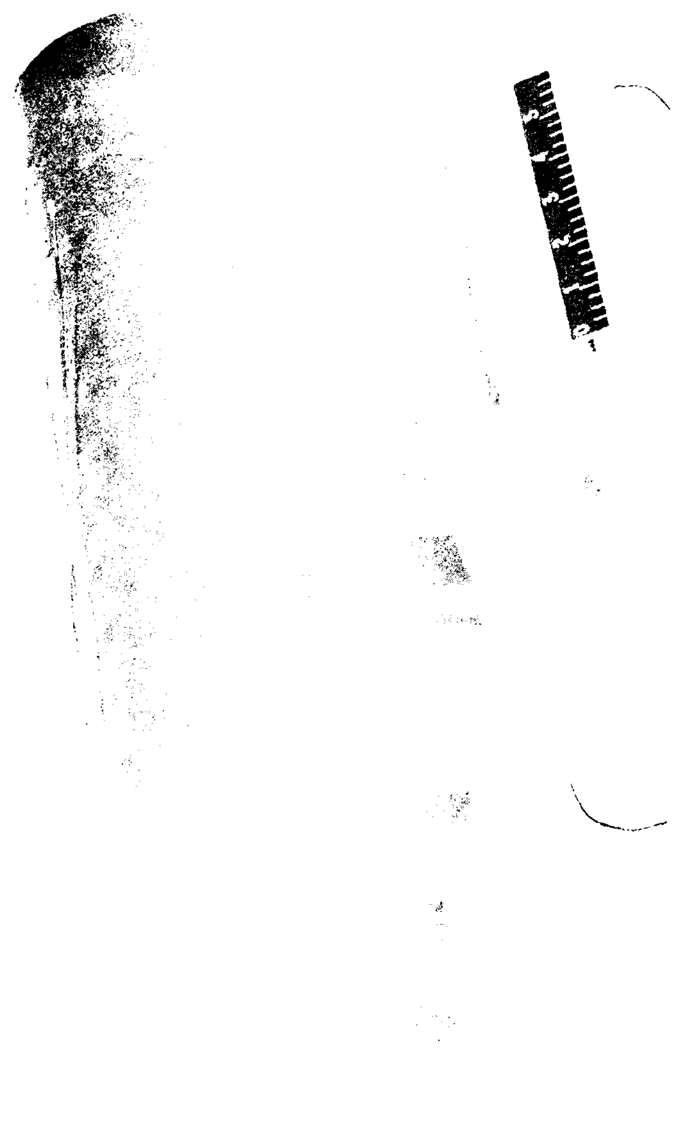
5. Angular dependence of quantum yield of a tungsten photocathode at four wavelengths in the far ultraviolet[6].

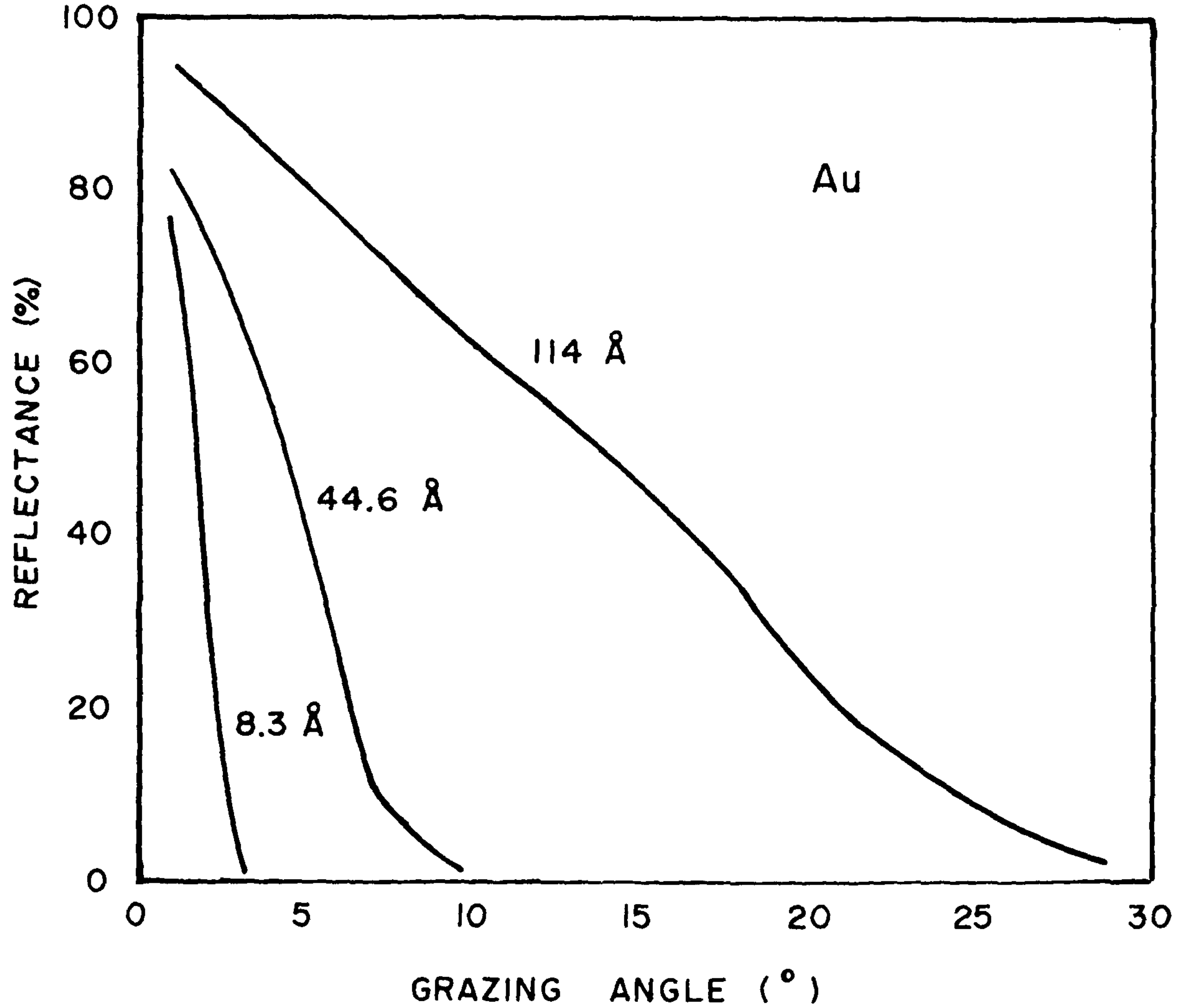
6. Quantum yields of CsI photocathodes in the far ultraviolet (500-1000 A)[7,8] and in the soft X-ray region (15-300 A)[4,5].

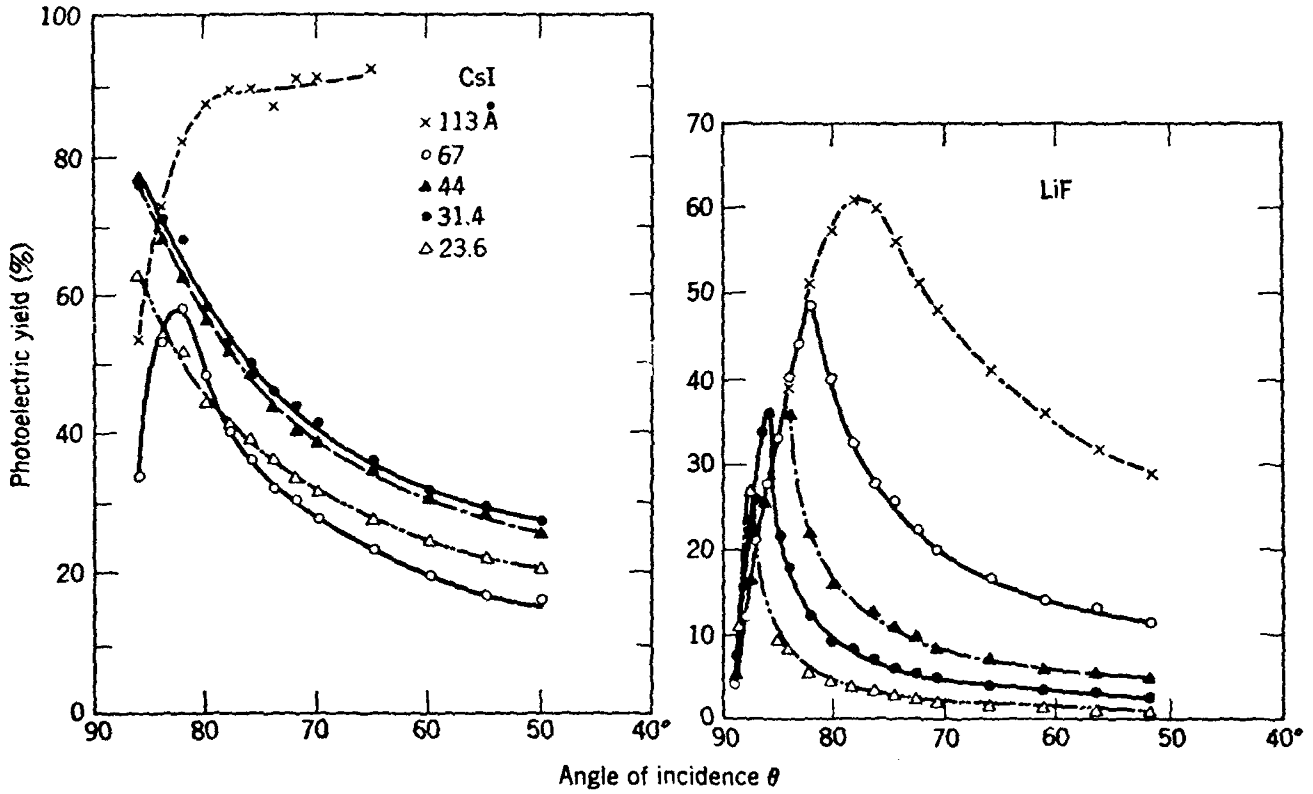
7. Grazing-incidence concave-grating electronographic spectrograph using electrostatic focusing.

8. Grazing-incidence concave-grating electronographic spectrograph using magnetic focusing.

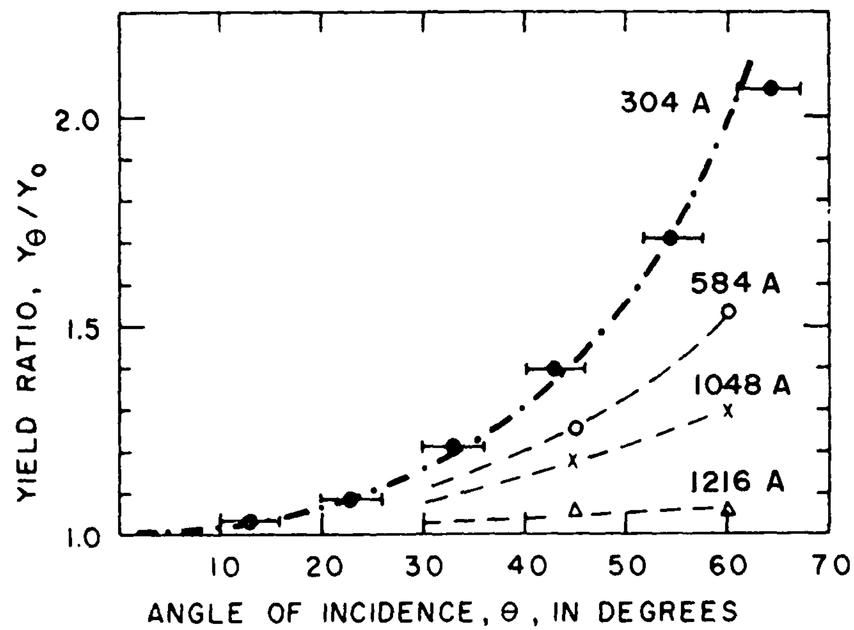

TOP VIEW
CONCAVE GRATING
INCOMING LIGHT
ENTRANCE SLIT
PHOTOCATHODE (ON ROWLAND CIRCLE)
PHOTOELECTRONS
SPECTRUM
ZERO ORDER IMAGE
NUCLEAR TRACK PLATE
ACCELERATING RINGS
SOLENOID COIL
- 20KV
SIDE VIEW
-20KV
PHOTOELECTRONS
ENTRANCE SLIT & SPECTRUM
NUCLEAR TRACK PLATE
CONCAVE GRATING
SOLENOID COIL



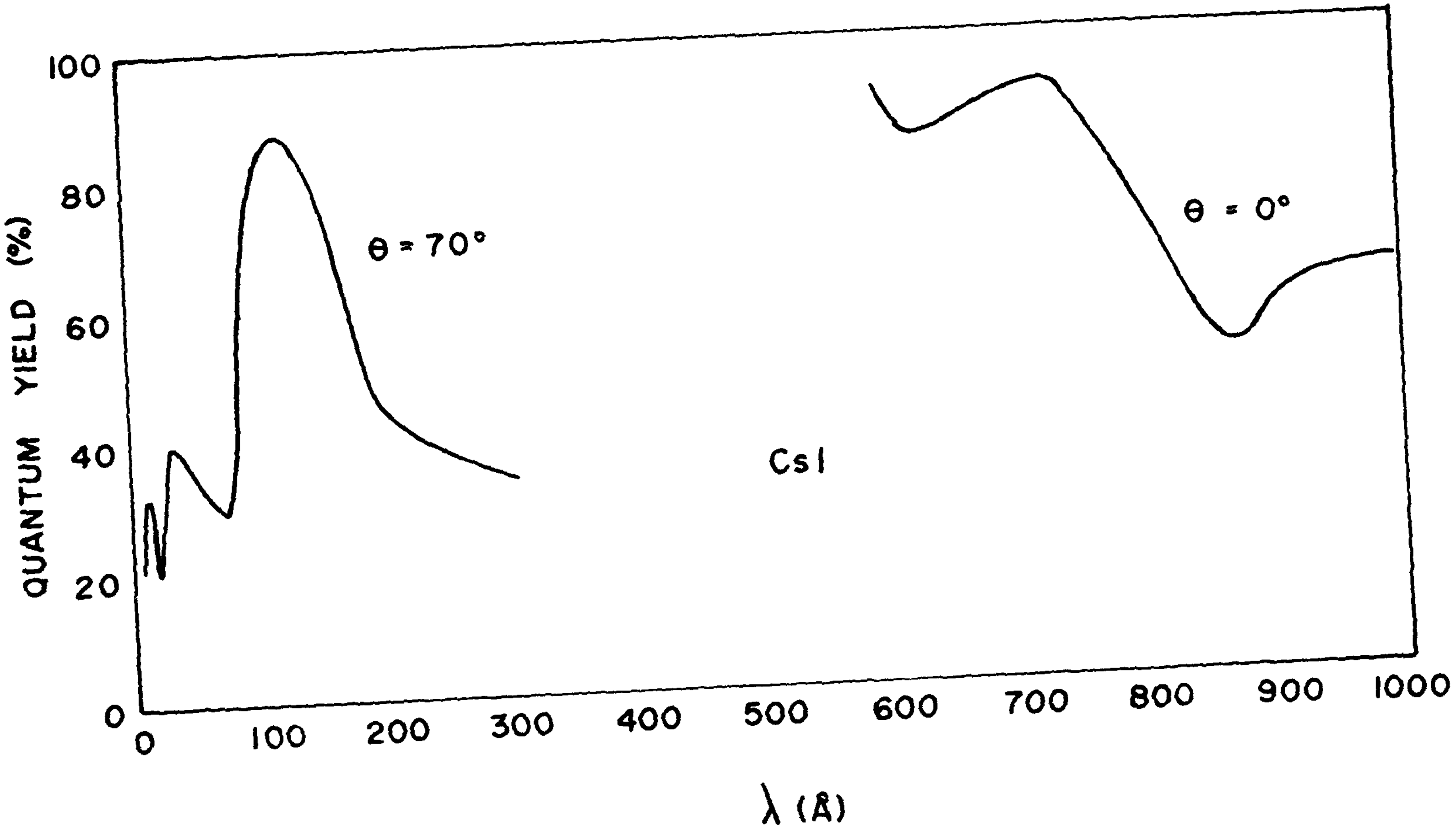

Au
114 Å
44.6 Å
8.3 Å
REFLECTANCE (%)
100
80
60
40
20
0
0
5
10
15
20
25
30
GRAZING ANGLE (°)

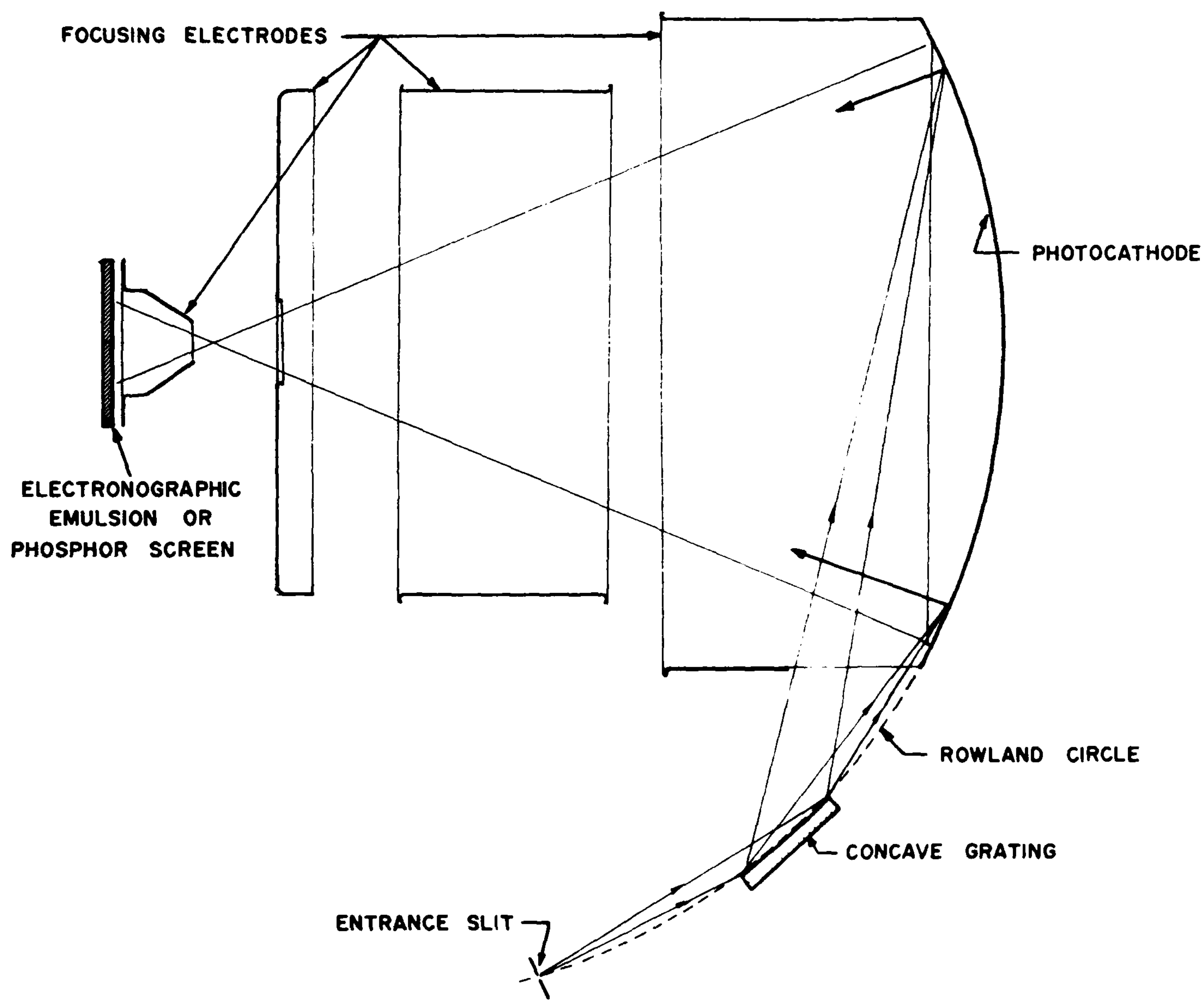


CsI
× 113 Å
○ 67
▲ 44
● 31.4
△ 23.6
LiF
Photoelectric yield (%)
Angle of incidence θ

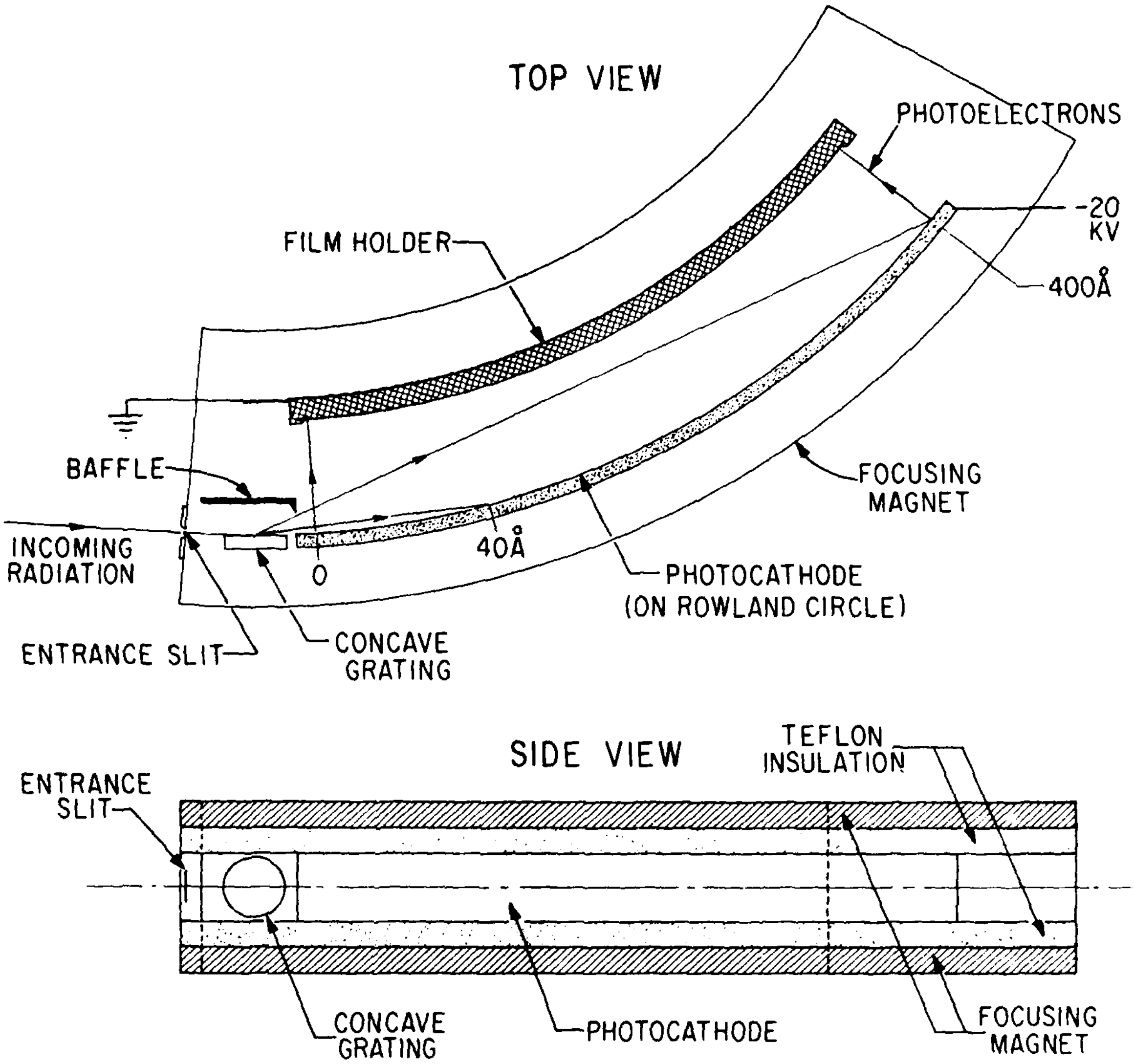


304 A
584 A
1048 A
1216 A
YIELD RATIO, $Y_\theta / Y_o$
2.0
1.5
1.0
10
20
30
40
50
60
70
ANGLE OF INCIDENCE, $\theta$, IN DEGREES


QUANTUM YIELD (%)
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
1000
λ (Å)
θ = 70°
θ = 0°
CsI



FOCUSING ELECTRODES
PHOTOCATHODE
ELECTRONOGRAPHIC EMULSION OR PHOSPHOR SCREEN
ROWLAND CIRCLE
CONCAVE GRATING
ENTRANCE SLIT


TOP VIEW
PHOTOELECTRONS
-20 KV
400Å
FILM HOLDER
BAFFLE
INCOMING RADIATION
0
40Å
FOCUSING MAGNET
PHOTOCATHODE (ON ROWLAND CIRCLE)
ENTRANCE SLIT
CONCAVE GRATING
SIDE VIEW
TEFLON INSULATION
ENTRANCE SLIT
CONCAVE GRATING
PHOTOCATHODE
FOCUSING MAGNET

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30 September 1971

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