Escape Depth for Excited Photoelectrons in KBr Films*

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Abstract

Quantum yields for backward and forward photoemission from evaporated KBr films have been measured as a function of film thickness. From the results of photoelectric yield measurements, the attenuation length for photoelectrons excited at hν = 10.2 eV was found to be approximately 180 Å, which is slightly greater than the absorption length for the photons. The measured attenuation length was used to estimate the mean free path for electron-phonon collisions.

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Introduction

Recent measurements[1] of photoemission from evaporated alkali halide films in the vacuum ultraviolet have shown that the photoelectric yields of some alkali halides are more than 0.5 at some photon energies above 9 eV. The relatively high yield implies that the escape depth for photoexcited electrons in these photoemitters is larger than the absorption length for the photons. In order to obtain further evidence that this is the case, the range of the excited electrons must be investigated. The purpose of the present work has been to determine the attenuation length of the excited photoelectrons in evaporated KBr films by measuring the quantum yield as a function of film thickness. It is shown that the results of the experiments are useful in estimating the mean free path for electron-phonon collisions in KBr.

Attenuation Length

The escape probability[2] of an electron excited at a distance x from the surface of a solid-vacuum barrier is given by

$$P(x) = p_o\, e^{-x/L}, \qquad (1)$$

where p_o is a constant for a given $h\nu$ and L is the attenuation length. It should be noted that L depends on the mean free paths for inelastic and elastic collisions. A method of relating L to various values of mean free paths has been discussed by Stuart, Wooten, and Spicer[3].

In using the exponential probability expression to calculate the photoelectric yield, we assume that the incident photons of energy $h\nu$ produce electrons of average kinetic energy E. The value of E may vary with $h\nu$. Now consider a photoemissive film of thickness T as shown in Fig. 1. The quantum yield in number of emitted electrons per absorbed photon can be represented by

$$Y = p_0 \int_0^T \alpha e^{-\alpha s} \, e^{-(T-s)/L} \, ds \Big/ \int_0^T \alpha e^{-\alpha s} \, ds \quad , \tag{2}$$

where α is the absorption coefficient of the photoemissive layer. Upon evaluating the integrals in Eq. (2), we find

$$Y = \alpha L p_0 \left(e^{-\alpha T} - e^{-T/L}\right) / (1 - \alpha L)(1 - e^{-\alpha T}) \tag{3}$$

It should be noted that optical reflection and electron scattering at the boundaries were not considered in the derivation of the yield equation.

Experimental Method

Quantum-yield measurements were made on KBr films evaporated in situ in a vacuum of 10^{-7} Torr. The incident radiation of a particular wavelength was obtained by means of a one-meter normal incidence vacuum monochromator. Fig. 2 illustrates the experimental arrangement. The sample chamber is shown in Fig. 3. It is similar to the apparatus[4] previously described; the only difference is that the substrate holder and collector are mounted on a rotatable feedthrough for measurements of forward emission as well as backward emission. Backward photoemission refers to the situation illustrated in Fig. 1.

Electrical connection between the evaporated layer and the electrometer lead was made by a circular strip of silver paint on a thin LiF substrate. The LiF crystal was initially coated with a thin film of gold to ensure adequate electrical contact with the KBr film, which was evaporated over the gold film. The backward photoemission current from the gold film was small in comparison with that from the KBr film at 10.2 eV.

The thickness of the evaporated film was determined by transmission measurements at 10.2 eV. The value[5] of α for KBr at 10.2 eV is about 6×10^5 cm^{-1}. Absorption measurements were made in order to see how the spectral absorption of the evaporated film compare with the reported data on KBr. The results shown in Fig. 4 are in agreement with those of Philipp and Ehrenreich[5].

Results and Discussion

As shown in Fig. 5, the yield for backward photoemission from KBr at $h\nu = 10.2$ eV decreases with increasing thickness. For $p_o = 0.34$ and $L = 180$ Å, the calculated curve from Eq. (3) fits the yield data for thicknesses greater than 150 Å. The data obtained at thicknesses greater than 100 Å are probably more reliable for comparison with Eq. (3). The lack of agreement at small thicknesses may be attributed to photoemission from the substrate and other boundary effects which we have neglected in deriving Eq. (3). It is interesting to note that the attenuation length L is slightly greater than the absorption length for the photons in this case.

Inasmuch as L has been determined experimentally, it is worthwhile to estimate the mean free path of the excited electrons in KBr. In this case the mean free path for electron-electron collisions is probably large in comparison with that for electron-phonon interaction. Therefore we will assume that the electrons excited at 10.2 eV lose energy only by electron-phonon collisions. For $h\nu = 10.2$ eV and a photoelectric threshold of 7.8 eV, the average kinetic energy of the excited photoelectrons is probably 1.2 eV. Using the relationship $E = 3kT_e/2$, we find that kT_e is about 0.8 eV. Since the phonon energy E_r for KBr is approximately 0.015 eV, we have the condition $kT_e >> E_r$. Consequently, we may consider the photoelectrons as hot electrons. According to theory[6], a relationship between the mean free path ℓ and the attenuation length L is given by

$$\ell^2 \approx 3E_rL^2/kT_e \qquad (4)$$

for $kT_e >> E_r$. Thus for L = 180 Å the mean free path is approximately 42 Å.

From a knowledge of the mean free path we may estimate the collision frequency f from the relation

$$f = u/\ell \quad , \qquad (5)$$

where u is the velocity which can be computed from $E = m\,u^2/2$. For E = 1.2 eV the electron velocity is about 6.5×10^7 cm/sec. Using the values we have for ℓ and u, we obtain a frequency of about 1.6×10^{14} sec^{-1}, which is in agreement with the estimate given by Seitz[7].

In addition to the backward photoemission measurements, the forward emission was investigated as a function of thickness. The results are shown in Fig. 6. The yield curves appear to saturate at about 200 Å. However, a gradual increase in yield is noticeable at larger thicknesses, especially for higher photon energies. The saturation effect is in agreement with the calculated yield for forward photoemission. It can be shown that the quantum yield in number of emitted electrons per incident photon is given by

$$Y_i = \alpha L p_o \left(1 - e^{-(\alpha + 1/L)T}\right) / (\alpha L + 1) \qquad (6)$$

For large values of T, the yield Y_i is represented by

$$Y_i = \alpha L p_o / (\alpha L + 1) \quad . \qquad (7)$$

If we use the values from the backward-emission measurements for p_o and L at 10.2 eV, Eq. (7) gives a limiting yield of about 0.18, which is in agreement with the experimental data for thicknesses of about 200 Å.

No attempt has been made to explain the additional rise in yield at thicknesses greater than 300 Å. One might suspect that the increase in yield is due to surface charges. Since KBr is an insulator, there is a possibility of charging the photoemissive surface when the film is sufficiently thick. It is well known that high electric field intensity within the film may introduce enhanced emission by producing impact ionization or field emission.

The quantum yield for forward photoemission from a KBr film of 630 Å thick is higher than the yield reported by Taft and Philipp[8]. The discrepancy may be due to different film thickness.

Footnotes and References

* Supported by NASA Grant NsG-328.

1. Duckett S. W. and Metzger P. H., Phys. Rev. 137, A953 (1965); Metzger P. H., J. Phys. Chem. Solids, 26, 1879 (1965).
2. Spicer W. E., Phys. Rev. 112, 114 (1958).
3. Stuart R., Wooten F. and Spicer W. E., Phys. Rev. 135, A495 (1964).
4. Pong. W., J. Appl. Phys. 37, 3033 (1966).
5. Philipp H. R. and Ehrenreich H., Phys. Rev. 131, 2016 (1963).
6. Baraff G. A., Phys. Rev. 135, A528 (1964).
7. Seitz F., Phys. Rev. 76, 1376 (1949).
8. Taft E. A. and Philipp H. R., J. Phys. Chem. Solids 3, 1 (1957).

Captions

Fig. 1 Backward photoemission from a photoemissive film of thickness T. Photoelectrons are produced by radiation which passed through the LiF substrate.

Fig. 2 A sketch of the experimental arrangement: vacuum uv monochromator, sample chamber, and ion-pump system.

Fig. 3 Spectral absorption of evaporated KBr film. The absorption coefficient at 10.2 eV was assumed to be 6 x 10^5 cm^{-1} and the values at other photon energies were calculated from optical-density data.

Fig. 5 Backward photoemission yield of evaporated KBr film at 10.2 eV. The yield Y in number of emitted electrons per absorbed photon decreases with increasing thickness.

Fig. 6 Forward photoemission yield of evaporated KBr film at different photon energies. The yield Y_i in number of emitted electrons per incident photon increases with increasing thickness.

Fig 1

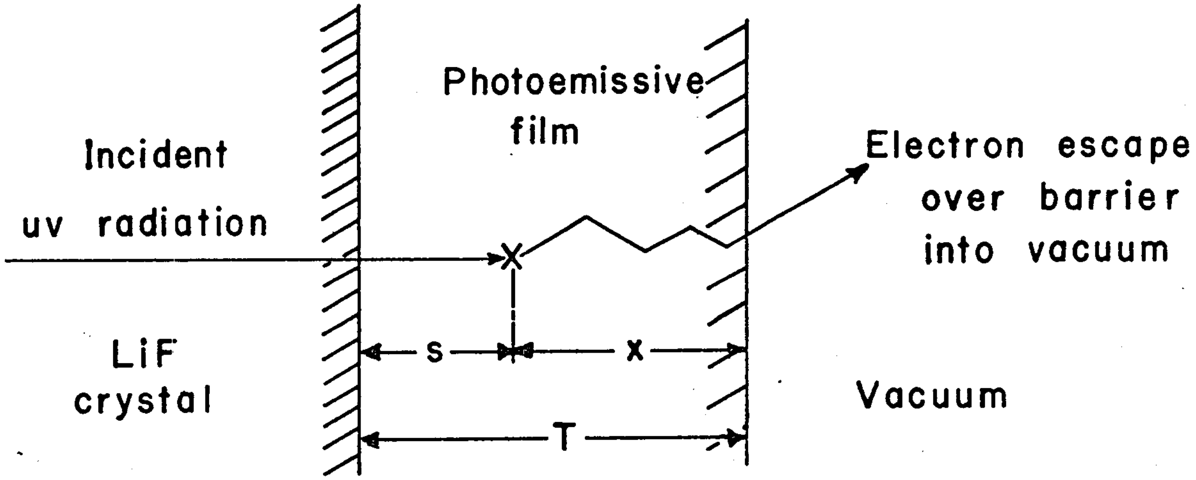
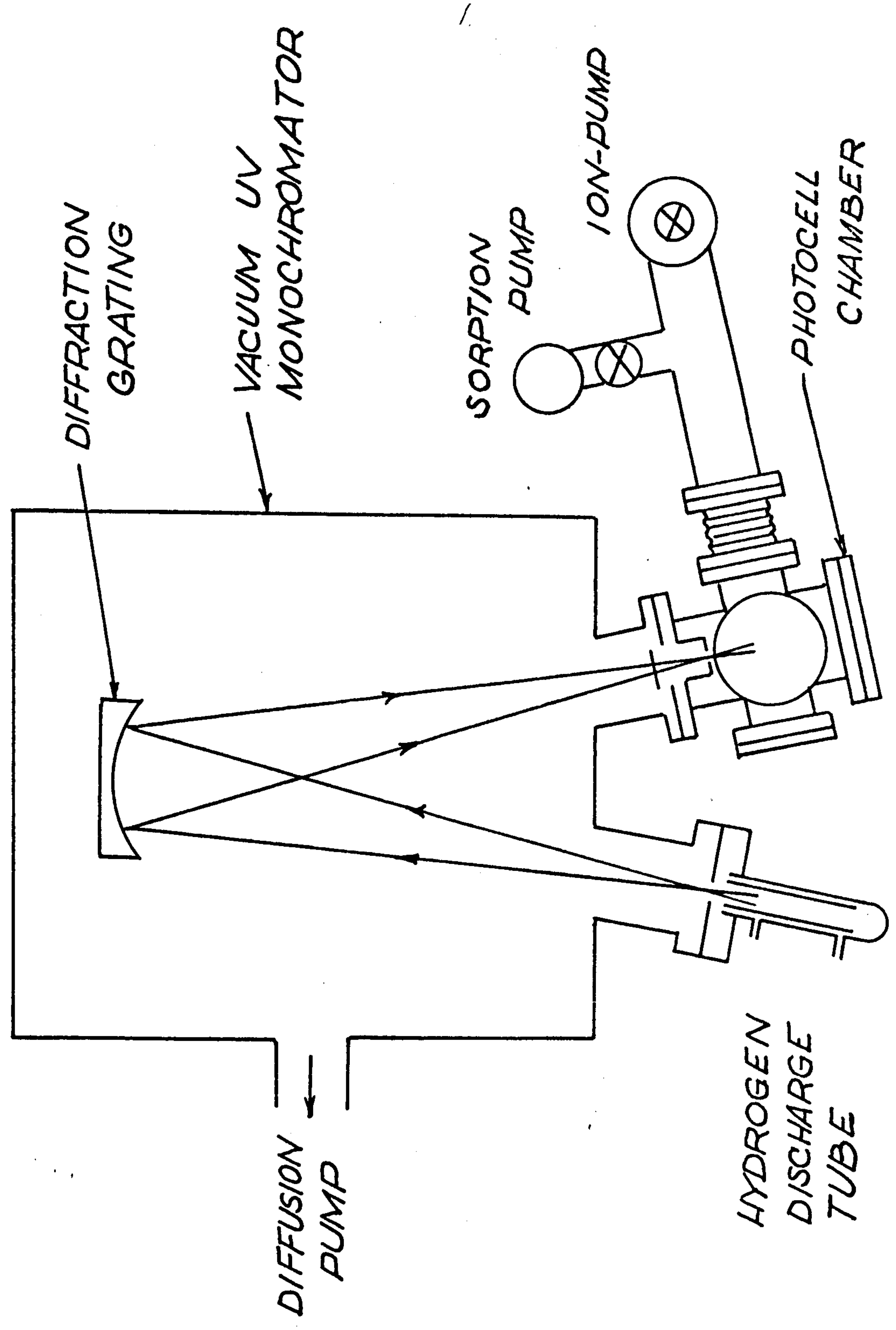

Incident
uv radiation
LiF
crystal
Photoemissive
film
Electron escape
over barrier
into vacuum
Vacuum
s
x
T

Fig 2.



DIFFRACTION GRATING
VACUUM UV MONOCHROMATOR
SORPTION PUMP
ION-PUMP
PHOTOCELL CHAMBER
HYDROGEN DISCHARGE TUBE
DIFFUSION PUMP

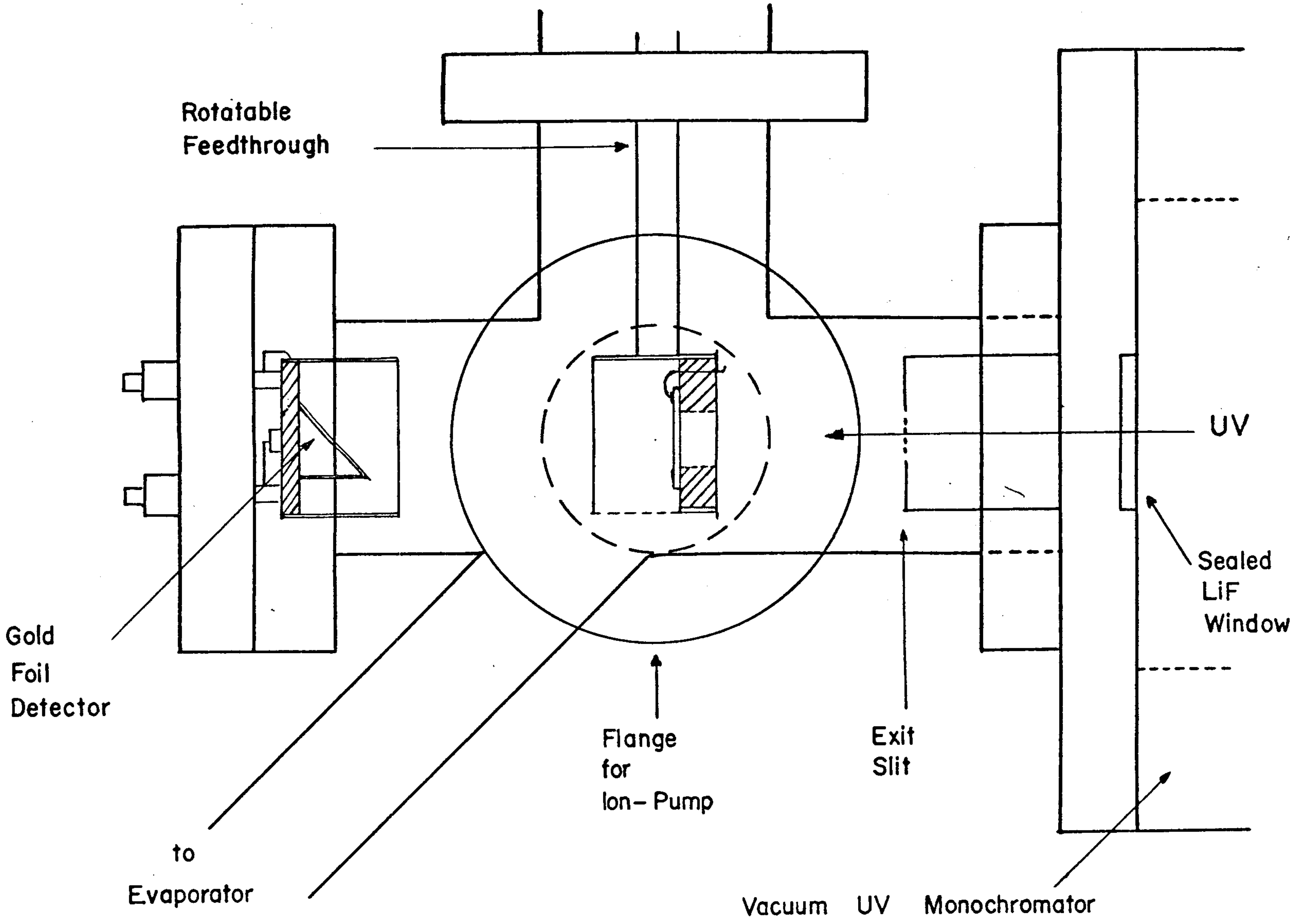
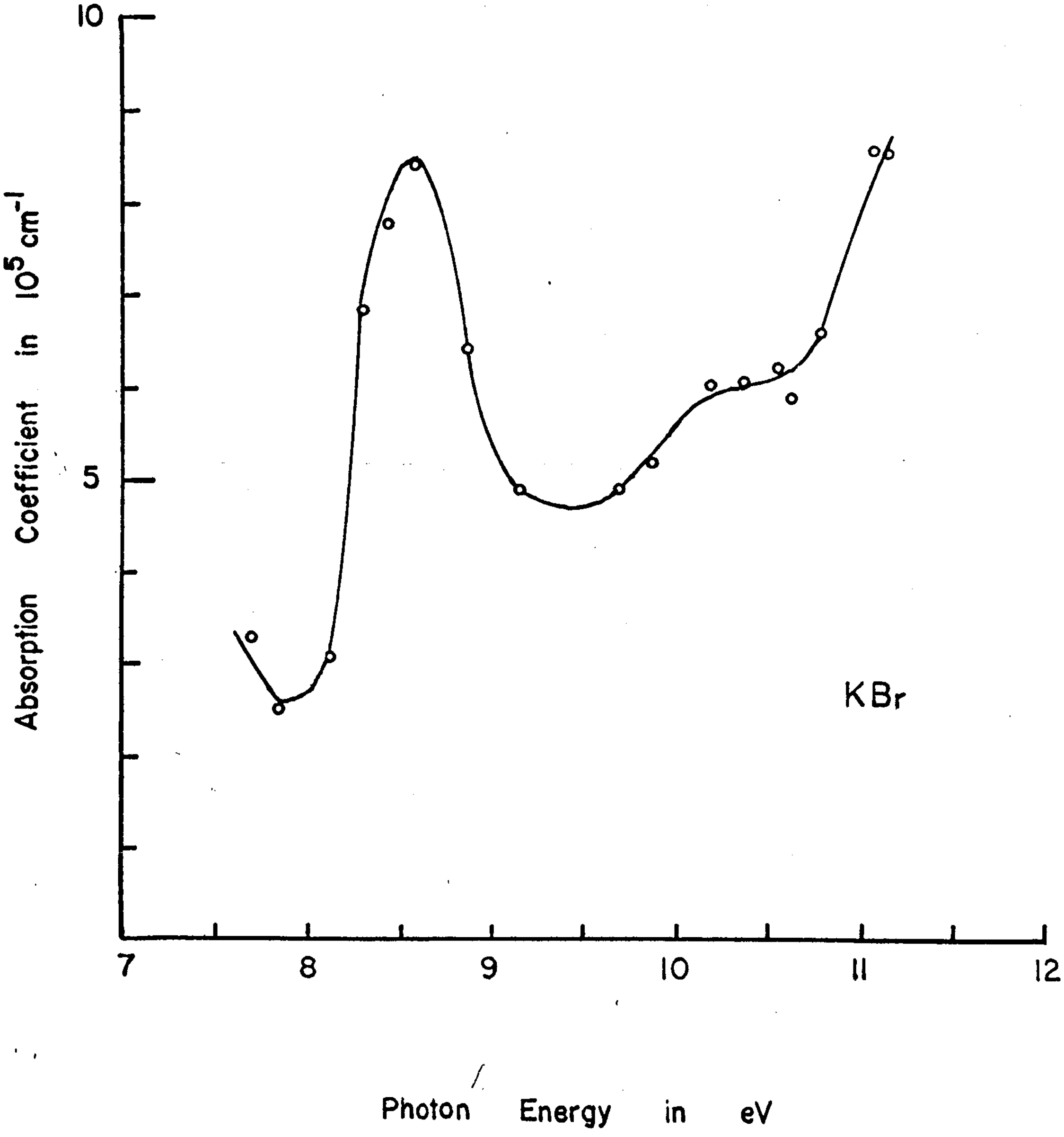

Rotatable Feedthrough
UV
Gold Foil Detector
Sealed LiF Window
to Evaporator
Flange for Ion- Pump
Exit Slit
Vacuum UV Monochromator

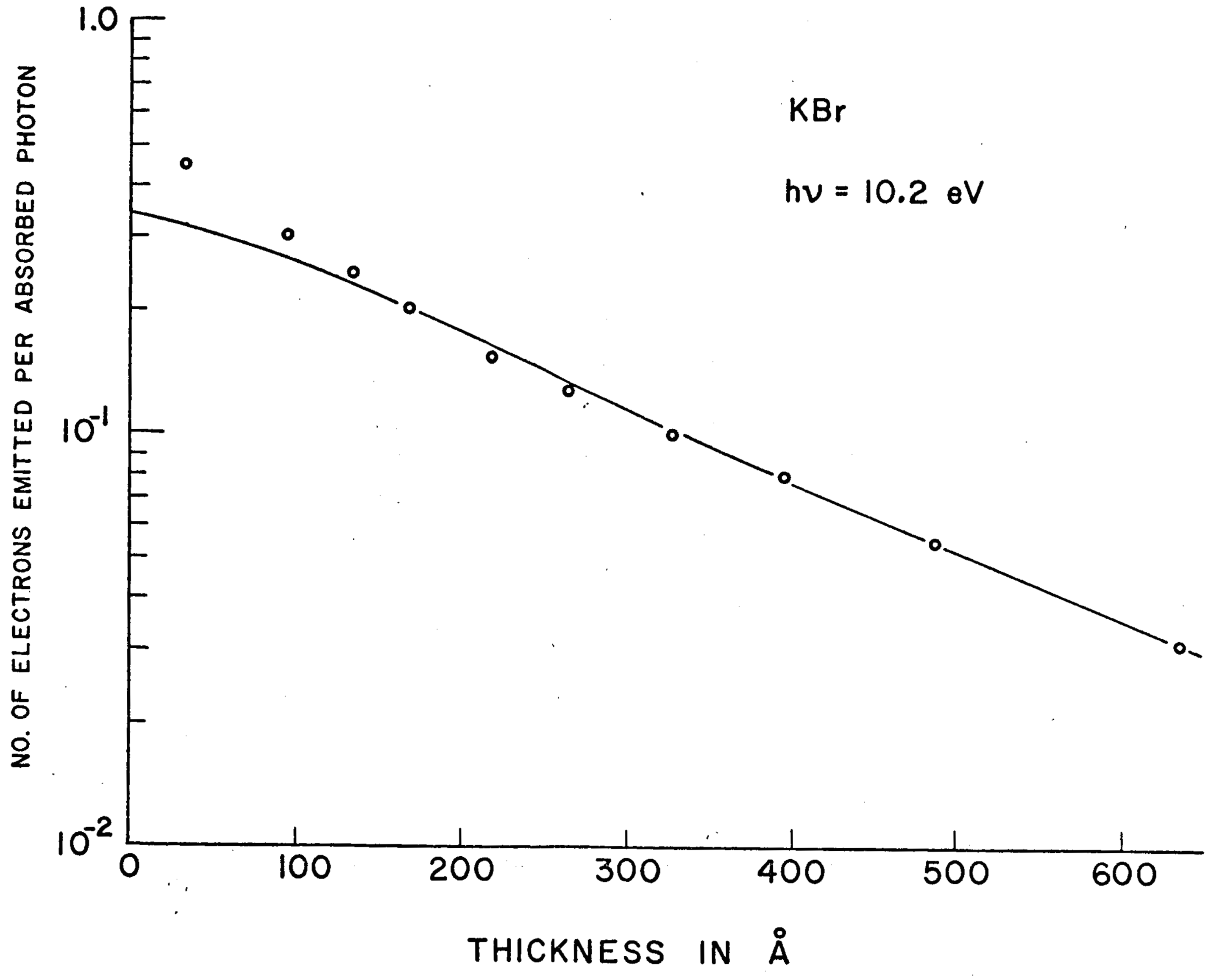
Fig 3

Fig. 4.



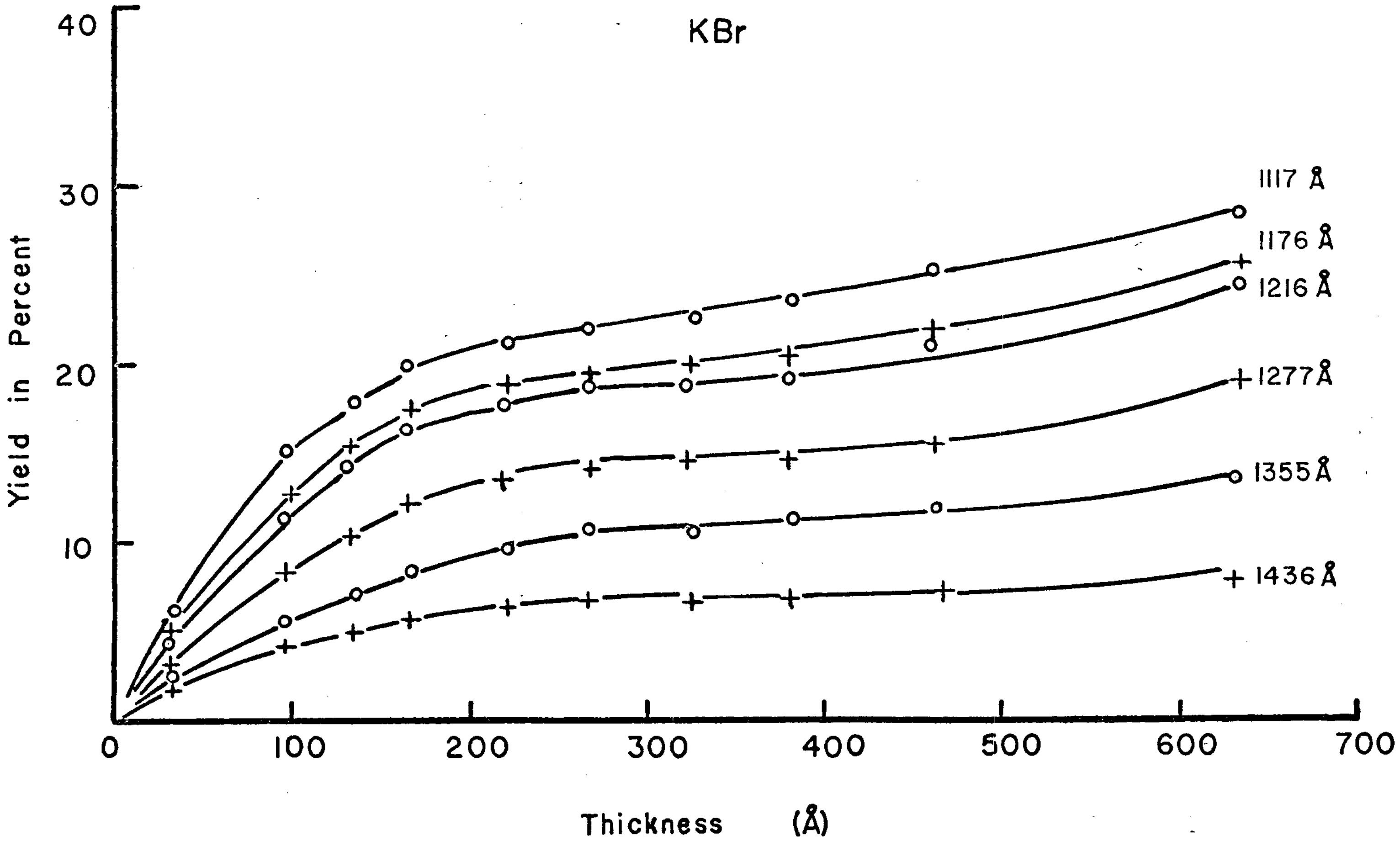
10
5
Absorption Coefficient in $10^5 \, cm^{-1}$
KBr
7
8
9
10
11
12
Photon Energy in eV

Fig. 5



1.0
10⁻¹
10⁻²
NO. OF ELECTRONS EMITTED PER ABSORBED PHOTON
KBr
hν = 10.2 eV
0
100
200
300
400
500
600
THICKNESS IN Å

Fig 6


KBr
Yield in Percent
40
30
20
10
0
100
200
300
400
500
600
700
Thickness (Å)
1117 Å
1176 Å
1216 Å
1277 Å
1355 Å
1436 Å