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Malcolm M. Fowler and Richard C. Jared

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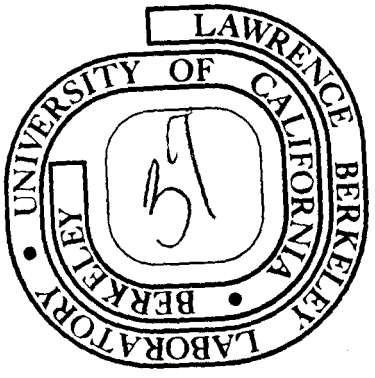

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A GAS IONIZATION COUNTER FOR PARTICLE IDENTIFICATION*

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ABSTRACT

A method is described for the identification of products from nuclear reactions. A gas ionization counter is used as a thin (0.8 mg/cm^2) transmission detector in a counter telescope particle identification system. The response of the system is approximately linear in Z for the ions produced by heavy-ion induced fission of medium Z targets. Reaction products with Z up to $\approx$ 30 can be well resolved.

Methods of fabrication of entrance windows for the counter are discussed and a procedure for determination of the window thickness is presented. Generally entrance windows were either Formvar or VYNS with a thickness of 40 - 60 μg/cm^2.

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*Work performed under the auspices of the U. S. Atomic Energy Commission

1. Introduction

The advent of high energy heavy-ion accelerators has brought on a rapidly developing need for techniques to identify the products resulting from heavy-ion interactions.

One of the identification methods currently in use involves measurement of the energy loss of an ion in a thin transmission detector. The total remaining energy is also measured by one or more subsequent detectors. While numerous expressions for the rate of energy loss of an ion as a function of its energy, Z, A, and stopping medium have been derived, in simplest form the rate of energy loss is given by[1]):

$$\frac{dE}{dx} \propto \frac{MZ^2}{E} \qquad (1)$$

where Z is the effective atomic number of the ion. M and E are the mass and energy of the ion. If the total energy is known or measured, the signal from the transmission detector is proportional to MZ^2. M and Z can then be deduced from systematics or other measurements. Thin silicon surface barrier detectors are often used for transmission detectors and perform well for light ions. In cases where heavy ions of low energy are to be identified, the detector must be very thin to avoid completely stopping the ions. Furthermore, the thickness of the detector must be very uniform to achieve good resolution.

For ions of $Z = 10$-30 at energies of less than $\sim$ 100 MeV, it would be desirable to have a detector of from 1 to 4 microns thick (0.2 to 0.8 mg/cm^2). The current technology for production of silicon detectors is such that they are not very uniform in thickness, especially when very thin. The

much greater uniformity of a gas transmission detector gives it a distinct advantage over silicon detectors for heavy-ion investigations. The gas ionization detector described in this paper has a typical thickness of 0.8 mg/cm^2 and the only dead layer in the counter is the entrance window composed of 20 - 60 μg/cm^2 of plastic. Disadvantages of this type of counter relative to a solid state counter include poorer timing characteristics, the necessity of additional gas control equipment, and smaller signals due to the larger energy required to form an ion pair in the gas.

At the Lawrence Berkeley Laboratory, the group under Dr. S. G. Thompson has been extensively involved with on-line studies of heavy-ion reactions and as the shortcomings of thin solid-state transmission detectors became apparent an effort to develop a gas counter was started. The resulting counter is reported here.

2. Description of the telescope

The gas ionization counter is shown in fig. 1. Ions, shown by a dotted line in fig. 1, pass through the window, traverse the gas losing energy and are finally stopped in a gold surface barrier detector. The electrons formed along the path drift up through the grid (dashed lines) and are collected by the plate shown at the top of fig. 1.

The housing of the counter is fabricated from rectangular extruded aluminum tubing (1 × 2.25 × 4 inches I.D.) with a plate of 0.25 inch aluminum welded to the ion entrance end (front) of the counter. The aluminum plate serves as support for the entrance window assembly and the magnetic yoke. The other end (back) of the counter is covered with a 3/8 inch thick brass plate sealed to the housing with an O-ring. The field effect transistor and associated components which form part of the charge sensitive loop of the preamplifier are located on this cover of the counter. The back cover also provides all of the necessary feed-

throughs and supports the various internal structures. In this way the internal parts are easily accessible during manufacture and in subsequent maintenance. The magnetic yoke of mild steel is mounted around the entrance window of the counter. The yoke is fitted with a samarium-cobalt permanent magnet (1 × 1 × 0.25 inches) that supplies the magnetic field (∿ 1000 gauss) to remove any external electrons that could otherwise enter the counter. The entrance window assembly is fabricated from a 3/8 inch NF stainless steel allen head capscrew. The window itself is made of VYNS[2]) (40 ± 20 μgm/cm^2) and is attached to the inner end of the capscrew (see Appendix for details).

The grid is constructed by first preparing a rectangular frame from brass and then attaching a sheet of electro-formed mesh to the frame with epoxy resin. The mesh is made of nickel 0.001" thick and has 20 lines to the inch in each direction. The open area of the mesh used was 92 to 97%. Plastic shields on the sides of the grid structure are to prevent gas multiplication in regions where the electric field is very high because of the close proximity of the grid and the housing of the counter. The plate is made of gold plated brass. Both the plate and grid structures are positioned on polystyrene supports which are attached to the back plate.

3. Counting gas system

The gas in the counter must be maintained at constant density to ensure that the energy deposited by a given ion in the gas will remain constant. Regulation of the density is accomplished by a Cartesian manostat[3]) as shown in fig. 2. The Cartesian manostat and counter are

kept in close proximity to minimize any temperature differential between them. Counting gas supplied from a tank at high pressure flows through a variable leak valve, then through the counter and to the Cartesian manostat that controls the density, and finally to a mechanical vacuum pump. An oil manometer is used to monitor the pressure. The use of a continuous flow ($\sim$ 100 to 500 cc/min at 70 torr) gas system makes the counter less sensitive to materials that would normally poison the counting gas after only a few minutes. This ability to employ materials not usually used in ionization counters reduces the cost of construction.

4. Electronic system

The preamplifier, fig. 3, is of the charge sensitive type. The FET and associated components enclosed in the dashed line are located inside the ionization counter. Using this configuration, the measured resolution with a mercury relay pulser was $\approx$ 20 keV FWHM. The electronic resolution of the counter could possibly be improved by operating the plate at ground with the grid and case negative, thereby eliminating several of the components that contribute to the noise. However, better resolution is not warranted in most cases as the resolution is limited by the energy straggling of the ions traversing the counter. Improved resolution could be of value in cases where very little energy is deposited in the counter.

In some experiments[4]), a reverse biased diode was connected to the gate of the FET to protect it from damage in the event of a possible electrical discharge in the counter.

5. Discussion

The time necessary to collect the electrons on the plate is determined by the drift velocity of the electrons in the gas. This drift velocity of electrons is a function of the field and the gas pressure in the counter. With the operating conditions generally used, the velocity was about 4 to 6 cm per microsecond. Since the surface barrier detector subtends a finite solid angle, some ions may take paths of different average distance (and slightly different lengths) from the collector plate. This results in different average collection times associated with the various average distances from the ion track to the plate. The path of the ions is nominally 19 mm from the plate but can vary ± 2.5 mm when using a surface-barrier detector of 10 mm diameter. The maximum time variation due to different paths with a drift velocity of 5 cm/μsec is then,

$$\Delta t = \frac{\Delta L}{V_D} = \frac{0.5}{(5)} = 100 \text{ nsec} \qquad (2)$$

Furthermore, when the ion path is not exactly parallel to the plate, the electrons will not all arrive at the plate at the same time causing some changes in the apparent rise time of the signal.

The electrons also diffuse while drifting to the plate, and this diffusion is a potential problem is small gas counters of the type reported here. The average distance that electrons will diffuse while drifting a distance L in a uniform electric field x is given by[5]:

$$\bar{x} = \sqrt{\frac{4(0.0235)}{\pi}} \sqrt{\frac{L\eta}{x}} \qquad (3)$$

where η is the ratio of the energy of agitation of the free electrons to that of gas molecules. Unfortunately the value of η must be measured experimentally, and the value has not been found in the literature for the Ar-CH_4 counting gas mixture used. The value of η for pure argon is reported[6]) to be $\sim$ 250 for X/p = 1.0 Volts/cm·torr while the value of η for pure methane is given as 8.6 [7]). It seems likely that the value of η for the 90% Ar-10% CH_4 mixture used is between the values for the pure gases. Using the values of η for the pure gases as limits, the average lateral diffusion in a uniform electric field typical of normal operating conditions (30 v/cm) is between 0.70 cm and 0.13 cm. This potential problem was minimized in the counter by the focusing action of the electric field. Figure 4 is a plot of equipotential electrostatic lines in the center region of the counter. The parameters leading to the fields in fig. 4 are typical operating conditions (Grid at 100 V and Plate at 350 V).

While diffusion in a lateral direction can possibly lead to loss of electrons to the walls of the counter, diffusion parallel to the electric field will also cause variation in the signal obtained from the counter. The increased time spread in the arrival time of the electrons due to diffusion can be calculated with eq. (3). Since the value of η is not well known, the evaluation of this time jitter is imprecise. When the previously used values of η are used to estimate the contribution to the time jitter, a range of 26 to 140 nsec is obtained.

There must be sufficient electric field to prevent recombination; at the same time it must not be so great as to cause the electrons to undergo any gas multiplication. With typical operating conditions the

chamber has ≈ 10 times the field necessary to prevent recombination in the in the region of ionization[5]). With these same conditions the field is large enough on the edges of the grid (the point of highest field) that any electrons in this area will undergo gas amplification. The plastic shields on the edges at the grid are to prevent the electrons from entering this region.

The effects of the shields at the edges of the grid and the end zones on the front and back of the counter create potential areas where the counter could fail to collect all the electrons that are generated in the gas by the passage of an ion through the counter. These effects have been investigated with alpha particles. The possibility of end zones was investigated by placing a ^{241}Am source in the front of the counter. The energy loss in the ionization counter and in the surface barrier detector as a function of pressure was measured. From these measurements the dead layers were not experimentally observable and it is felt that they are < 1% of the total path length in the gas. In addition, an alpha source mounted in the center of the chamber gave 26.1 ± 1 eV per ion electron pair which is in good agreement with other measurements[8]).

The results of a third approach in which a ^{252}Cf alpha source was mounted in the front of the counter are shown in fig. 5. This figure shows the width of the pulse height distribution in the surface barrier counter and in the gas counter as a function of the energy loss in the gas counter. The electronic noise of the two systems has been subtracted before plotting the data. The figure shows that the width of the energy spectrum in the gas counter is (within experimental errors) exactly that which is expected

from straggling in the gas as is determined from that observed in the energy detector.

6. Experimental performance

Six of the counters have been built at Berkeley and are being used in experiments. The performance of the six counters was found to be very uniform. Figure 6 shows a map of energy deposited in the gas counter versus the energy observed at the surface barrier detector. These data were obtained in experimental work by the Dr. S. G. Thompson group. During collection of these data, the counting gas was P-10 (90% Ar, 10% CH_4) at a pressure of $\sim$ 60 torr. The grid and plate potentials were 100 V and 350 V respectively. The contour map shows that reaction products with atomic numbers from 5 to 30 are easily resolved at the energies observed in the reaction. Figure 7 is a spectrum of the energy measured in the ionization counter with a window on the energy counter. From these data it is seen that the peak to valley ratio at atomic number 27 is still about 2:1.

7. Conclusions and range of applicability

The gas ionization telescope has demonstrated ability to accurately measure the magnitude of energy losses using alpha particles. It has also been shown to be useful to experimental identification of reaction products by the Dr. S. G. Thompson group in the region ($6 < Z < 30$).

The counter may also be useful in determining the atomic numbers of even heavier ions such as that of fission fragments. It now appears to be a very good replacement for thin silicon detectors in most applications. The ultimate value of these proposed applications will be revealed only after more investigation into the use of gas ionization counters as delta energy detectors.

APPENDIX: Preparation and Measurement of Thin Foils for Entrance Windows

1. Introduction

The preparation of entrance windows for heavy-ion measurements poses some problem. It is desirable to have very thin windows to minimize energy degradation of the ions. The window must at the same time be strong enough to sustain the operating pressure of the counter and be mechanically durable enough to allow cycling of pressure during pump-down in acceleration facilities.

It would also be valuable to have the windows of high Z material from a range energy viewpoint and, last but not least, ease of fabrication must be considered. With these criteria in mind circular entrance windows have been prepared for the telescope from several materials with diameters of 2 mm and 4 mm. At this time it appears that Formvar[9]) and VYNS[2]) are the best materials from which to fabricate windows.

2. Preparation of windows

Windows of gold foil (300 $\mu g/cm^2$) have been prepared by bonding the free foil to window holders using Eastman-910 adhesive. These windows were found to be too fragile to support the pressure differential of 60 torr required for operation of the counter.

Windows of nickel foil 0.13 (130) microns thick (120 $\mu g/cm^2$) were prepared from commercial copper backed nickel foil. The nickel side of the composite foil was bonded to a window holder using Eastman-910 adhesive. The copper backing was then chemically etched off leaving the nickel. These foils (2 mm diameter) were found to be adequately strong to sustain the working

pressure of the counter but were sensitive to mechanical shock and somewhat difficult to fabricate.

Formvar windows have been prepared by lamination of either 12 films of 4 $\mu g/cm^2$ or 6 films of 8 $\mu g/cm^2$. The films were prepared by mechanically spreading a solution of Formvar in cyclohexanone on water[10]). The preparation of thick Formvar films has also been described by Grader et al.[11]). The window was prepared by bonding the film to the window holder with a dilute solution of acrylic in cyclohexanone. Several times problems were encountered when the acrylic glue was carried to the inner edge of the window by capillary action leaving a residue after evaporation of the solution. These problems encountered in lamination and bonding of the film to the holders led to the investigation of VYNS as a window material. However, it should be noted that, in all probability, Formvar is as good a material for windows as is VYNS.

VYNS films have been prepared by spreading the film on water as described by Pate and Yaffe[12]). Addition of xylene suggested by Lowenthal[13]) ($\sim$ 30% by volume) to the cyclohexanone solution of VYNS allows the solution to spread spontaneously on water giving films good uniformity that are free of pinholes. It was found that films as thin as 1 - 2 $\mu g/cm^2$ could be prepared in this way by adjusting the concentration of the VYNS-cyclohexanone-xylene solution. The films were generally made $\sim$ 10 $\mu g/cm^2$ and laminated to 50 - 60 $\mu g/cm^2$ for use as windows. After spreading on the water, the film was picked up with a wire frame and transferred to a ring 6.5 cm diameter. Several films could be laminated on one ring during this process with the film thickness being monitored between each lamination until the desired

thickness was reached.

The film was attached to the window holder by the following procedure. The holder was placed on end and wet with distilled water. The film was then lowered to contact the holder. The holder and film were then warmed with a heat-light until all of the water had evaporated. Several of the holders were prepared simultaneously from a single 6.5 cm diam. plastic film. It has been found that the windows bonded in this manner were vacuum tight and had the advantage that there was no possibility of the presence of extraneous glue or adhesive being carried to the inner edge of the entrance window by capillary action as was sometimes the case for Formvar windows bonded with acrylic.

3. Measurement of plastic foil thickness

Several methods have been proposed for determination of the superficial density of thin plastic films. Among the methods proposed are measurement of optical density, absorption of α and β^- particles, and weighing[14]). While each of these methods has some advantages, only weighing is a direct method requiring no calibration data. The weighing technique, however, is generally destructive to the film. In this procedure it is usually necessary to cut out and weigh a specific area free of any support to attain the requisite weighing sensitivity.

In view of the foregoing, it was felt that there was need for a rapid nondestructive method of determining the thickness of films in the region 10 - 100 $\mu gm/cm^2$. It has been noted[11,12,14]) that these films reflect light that is rather strongly colored due to interference effects,

and it was felt this property might lead to a determination of thickness. The conditions for constructive and destructive interference of light of a given wavelength λ are given by:

$$(n + \frac{1}{2})\lambda = 2\mu t \cos\theta \qquad \text{Transmission minimum} \qquad \text{(A1)}$$

$$n\lambda = 2\mu t \cos\theta \qquad \text{Transmission maximum} \qquad \text{(A2)}$$

where n is an integer, μ the index of refraction of the film and t the thickness of the film.

By determining the variation of optical transmission as a function of wavelength, one may deduce the film thickness. With the film situated perpendicular to a beam of light, the $\cos\theta$ term in eqs. (A1) and (A2) becomes unity and only a knowledge of the refractive index is necessary to determine the thickness. Knowledge of the density further allows calculation of the superficial density of the film. For the wavelengths of maximum transmission:

$$t = \frac{n\lambda}{2\mu} \qquad \text{(A3)}$$

or,

$$s = \frac{n\lambda\rho}{2\mu} = k(n\lambda) \quad , \quad k = \frac{\rho}{2\mu} \qquad \text{(A4)}$$

where s is the superficial density and ρ is the density. Table 1 summarizes these properties for VYNS and Formvar. Similar relations can be derived for transmission minima. When the films are thick enough that several maxima are observed, the thickness may be calculated from each maxima and averaged. The assignment of n to each maxima is effected by assigning a probable value of n to one maxima and then calculating the value of $n\lambda$ for each maxima. The value of $n\lambda$ will be a constant for all

maxima when n is assigned properly.

Typical UV-visible spectrophotometers have a wavelength range of 200 - 800 nm. The minimum wavelength measurable by the spectrophotometer determines the thinnest film ($\sim$ 9 $\mu g/cm^2$ for 200 nm) that can be measured directly. The thickest film measurable is determined by accuracy of placement in the spectrophotometer, by film uniformity, and by the diminishing interference effects as n becomes large.

The transmission spectra of VYNS films of several thicknesses are shown in fig. 8. The data in fig. 8 and table 2 indicate reliable measurements can be made to film thickness of greater than 200 $\mu g/cm^2$. Formvar films can be measured by the same technique and yield similar spectra.

If films thinner than $\sim$ 10 $\mu g/cm^2$ are to be measured, a piece of the film to be determined can be laminated to one already measured that is greater than 10 $\mu g/cm^2$ and the thin film determined by difference. Of course, this is no longer a non-destructive method and perhaps some other technique would be more attractive depending on conditions.

The accuracy of the method seems to be limited to the accuracy of determination of the location of the maxima (or minima). The method has been checked by weighing of several films and the agreement is excellent. (See Table 2). It is felt that the method should be accurate to $\pm$ 5%. If the spectrometer used has the capability of analyzing reflected light, the accuracy of the method could be improved.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support and encouragement of Dr. S. Thompson. The cheerful help of the shops and accelerator crews at the 88" cyclotron and HILAC was also appreciated.

Table 1. Physical properties of VYNS and Formvar

Film Material	Index of Refraction	Density (gm/cm^3)	k ($\mu g/cm^2 \cdot nm$)
VYNS	1.54	1.36	0.0442
Formvar 15/95s	1.502	1.229	0.0463

* * * * * * *

Table 2. Comparison of measured film thickness determined by various methods.

Film	Weighing ($\mu g/cm^2$)	Optical Absorption[a] (at 600 nm) ($\mu g/cm^2$)	Interference[b] ($\mu g/cm^2$)
1	3.0	2.6	--
2	5.5	6.5	--
3	8.3	9.6	--
4	14.8	14.3	--
5	--	14	12
6	--	16	13
7	17	16	18
8	23	--	23
9	35	--	36
10	87	--	95
11	199	--	215

[a]Method proposed by Pate and Yaffe[11].

[b]Method proposed in this work.

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[2]) This material is a polyvinylchloride-acetate copolymer (85% chloride, 15% acetate), supplied by Union Carbide, Bakelite Division.

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FIGURE CAPTIONS

Fig. 1. A cross-sectional view of the gas ionization telescope.

Fig. 2. Diagram of gas supply and regulation system.

Fig. 3. Simplified diagram of preamplifier. Components within the dashed line are inside the ionization counter.

Fig. 4. Equipotential lines in the center section of the counter for typical plate and grid voltages.

Fig. 5. Energy resolution of the gas detector and solid state detector as a function of the energy deposited in the gas detector.

Fig. 6. Map of energy deposited in the gas counter versus that observed at the energy detector.

Fig. 7. Spectrum of ionization events in coincidence with a constant energy window (20 - 25 MeV) in the energy counter.

Fig. 8. Optical transmission spectra of VYNS films of various thicknesses.

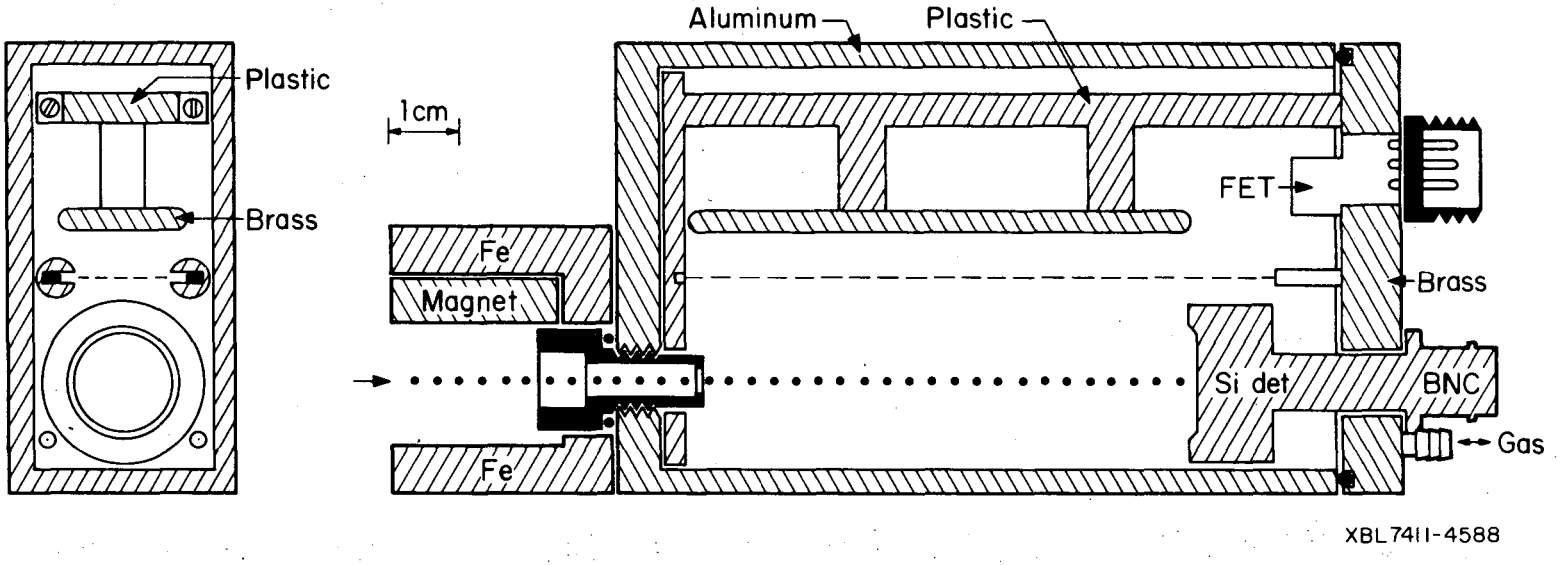
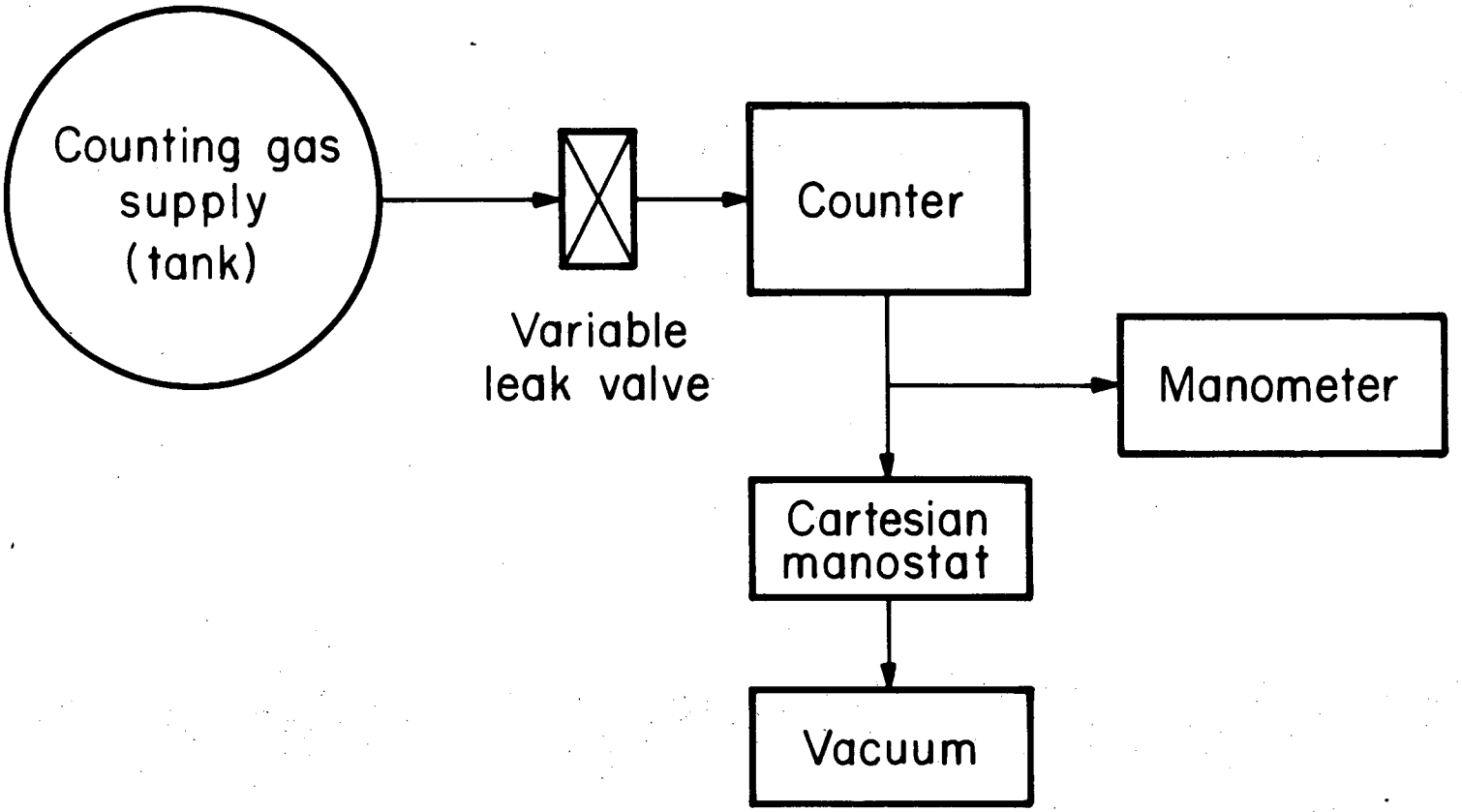

Plastic
Brass
1cm
Aluminum
Plastic
FET
Fe
Magnet
Brass
Si det
BNC
Gas
Fe
XBL7411-4588

Fig. 1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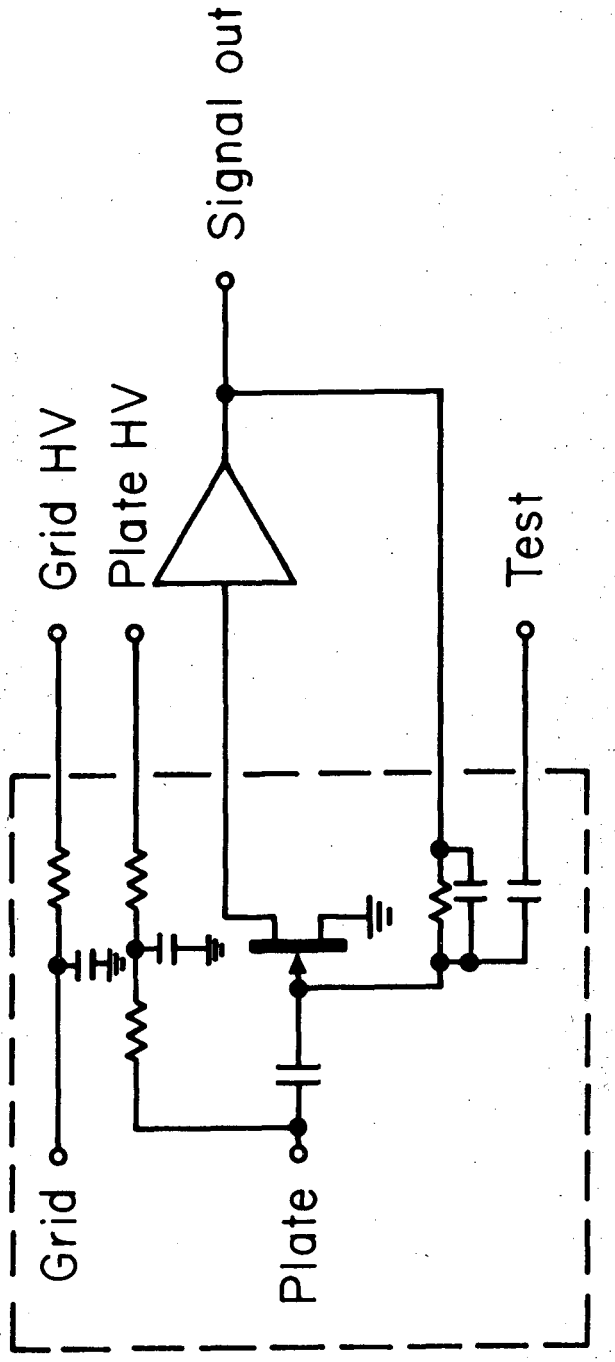
Variable leak valve
Counter
Manometer
Cartesian manostat
Vacuum
XBL7411-4594

Fig. 2



XBL7411-4591

Fig. 3

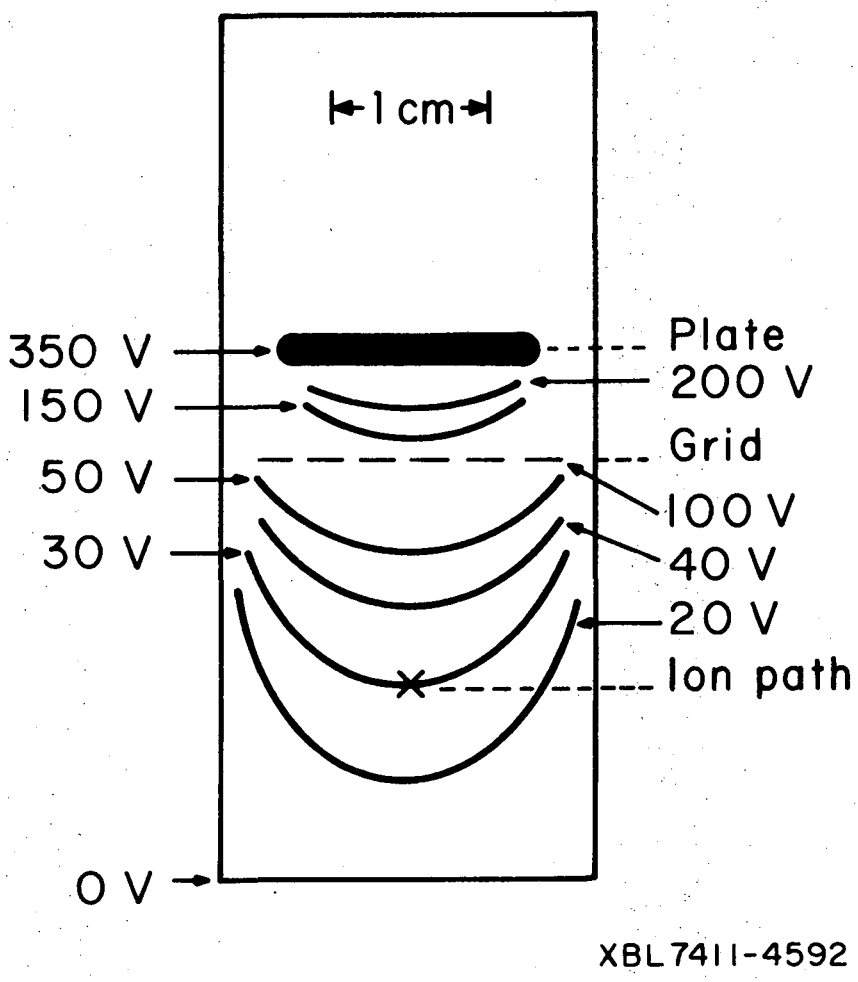

1 cm
350 V
150 V
50 V
30 V
0 V
Plate
200 V
Grid
100 V
40 V
20 V
Ion path
XBL7411-4592

Fig. 4

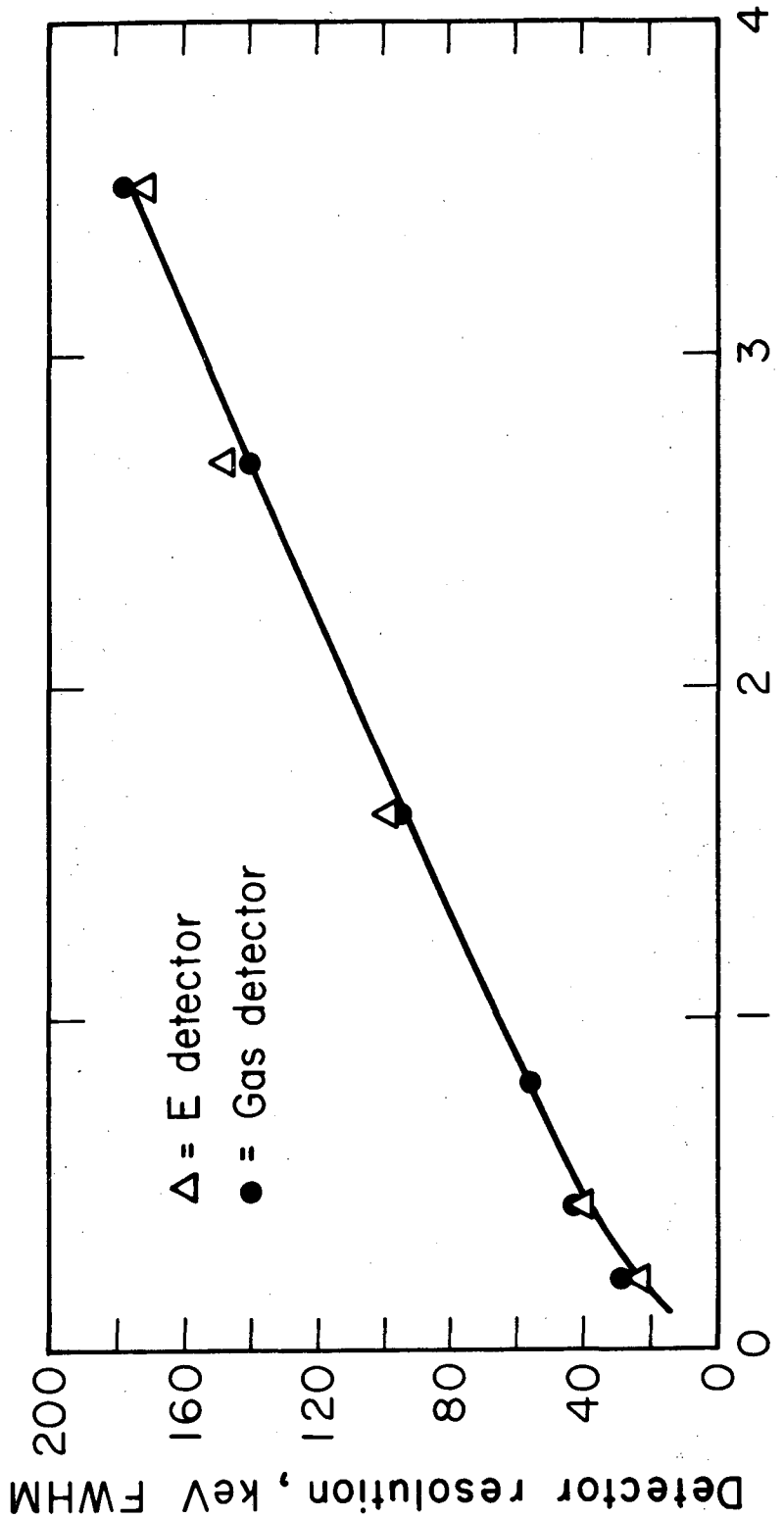


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Fig. 5

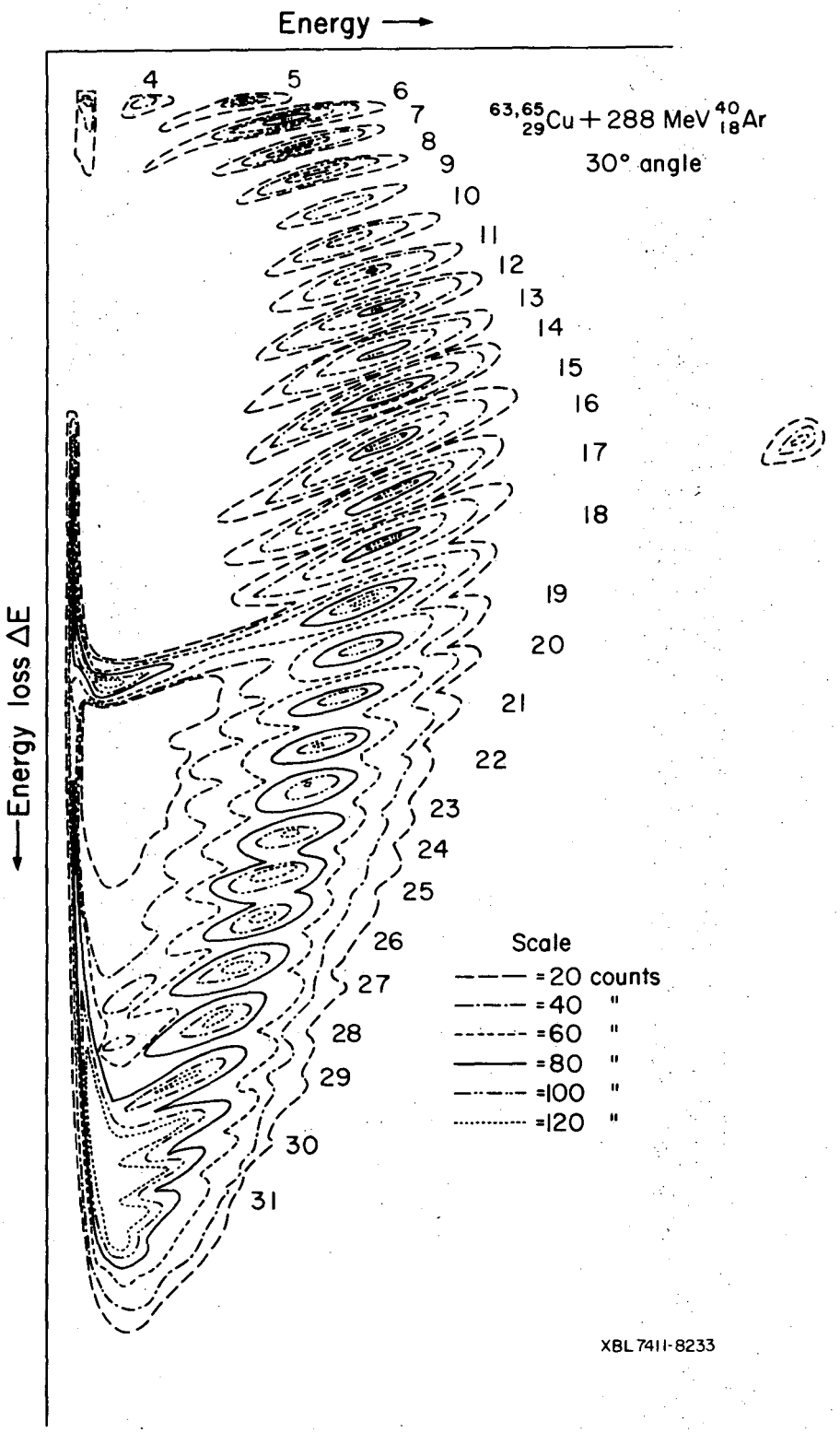
Energy →
←Energy loss ΔE
$^{63,65}_{29}Cu + 288$ MeV $^{40}_{18}Ar$
30° angle
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
Scale
——— = 20 counts
—·—·— = 40 "
------- = 60 "
——— = 80 "
—··—··— = 100 "
····· = 120 "
XBL 7411-8233

Fig. 6

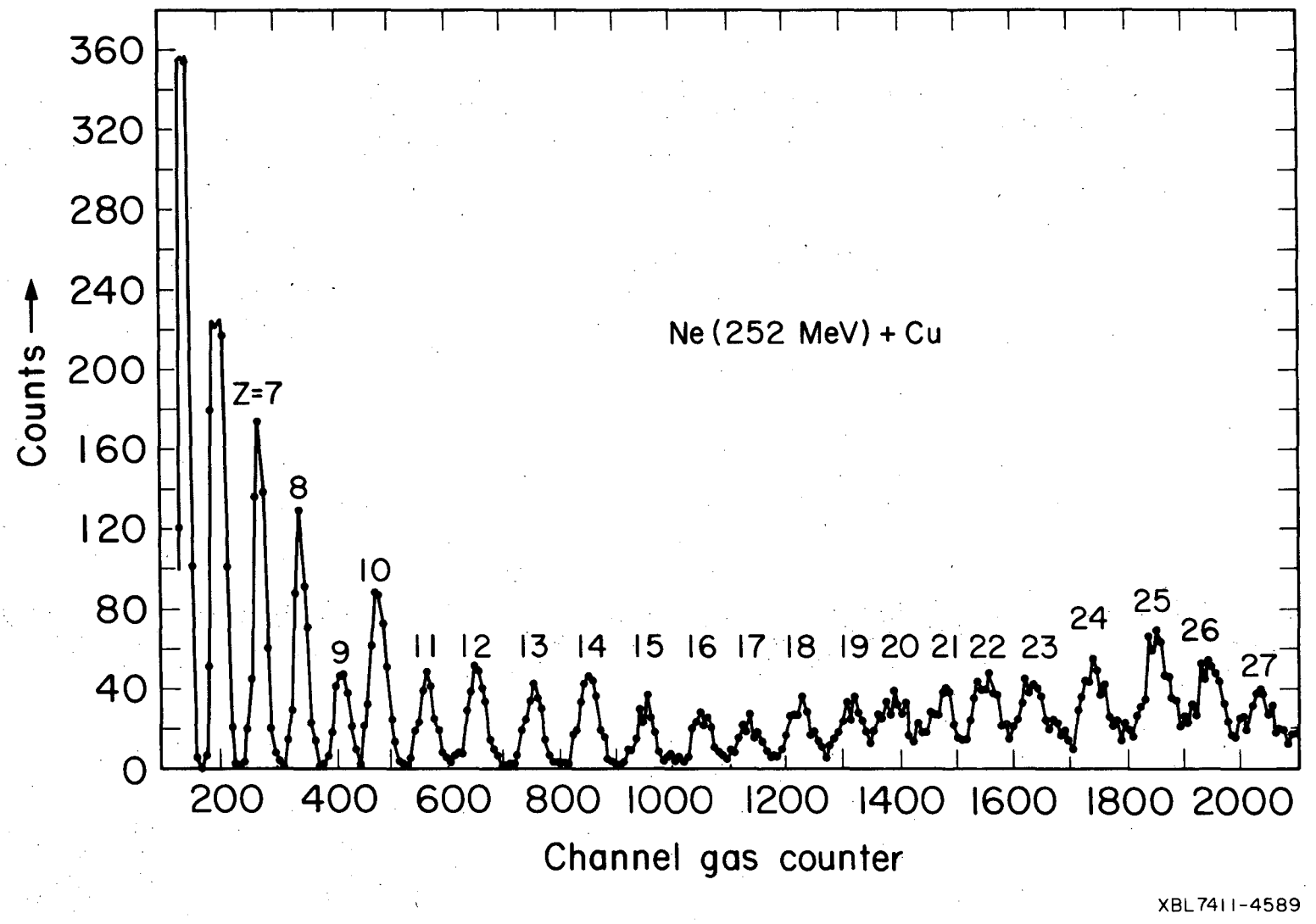
Ne (252 MeV) + Cu
Counts
Channel gas counter
Z=7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
0
40
80
120
160
200
240
280
320
360
200
400
600
800
1000
1200
1400
1600
1800
2000
XBL7411-4589

Fig. 7

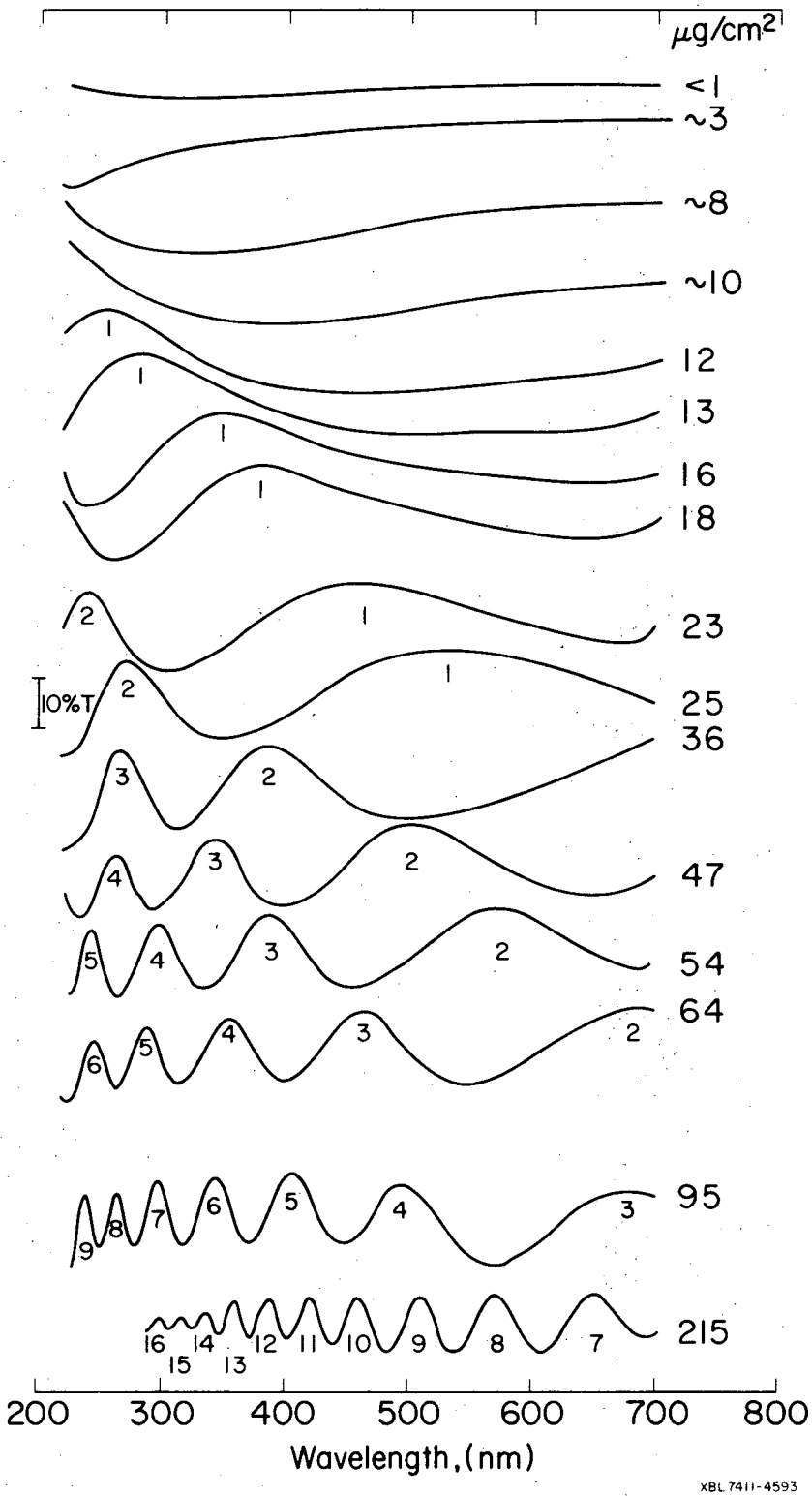
μg/cm²
<1
~3
~8
~10
12
13
16
18
23
25
36
47
54
64
95
215
10%T
200
300
400
500
600
700
800
Wavelength,(nm)
XBL 7411-4593

Fig. 8

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