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The study of some phenomena observed with monochromatic X-ray beams.

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A THESIS

entitled

" THE STUDY OF SOME PHENOMENA OBSERVED WITH

MONOCHROMATIC X-RAY BEAMS "

submitted in candidature for the degree of

PHILOSOPHIAE DOCTOR

of the University of Wales

by

G. Phylip Jones B.Sc.

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Physics Department,

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Sept 1953

BANGOR.



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SUMMARY.

The mass absorption coefficients of a number of pure elements (Beryllium, Carbon, Aluminium, Iron, Nickel, Copper, Zinc, Molybdenum and Palladium) have been measured for pure beams of Copper K α , and Cobalt K α , radiation.

The monochromatic beams were produced by the selective reflection of these wavelengths from the X-ray beam emitted by a rotating anode X-ray tube by means of a powdered crystal focussing monochromator and were detected by Geiger tubes connected to pulse counting equipment.

An attempt was made to measure the fluorescent absorption coefficients of these metals, as well as their total mass absorption coefficients, which include the scattering coefficients. The values obtained were (within the experimental error of these measurements) in agreement with the total absorption values, so that the part of the absorption coefficient due to the scattering of the X-rays is small for these wavelengths, and can be ignored in comparison with the fluorescent absorption. The measured absorption coefficients were in good agreement with those obtained by other workers, although they did not use such pure monochromatic X-radiation.

Measurements were also made with a beam of Chromium radiation which was not monochromatic but consisted of the Chromium K α , wavelength contaminated by the white radiation from the X-ray tube. In this case, the mass absorption coefficient varied with the thickness of material irradiated, but by graphical analysis of the transmitted intensity curves, the values at different wavelengths present in the beam could be determined. They were not as accurate as those carried out with the pure radiations.

The variation of the atomic absorption coefficients,

calculated from the results, with wavelength and atomic number, was investigated, and an empirical absorption formula deduced. It was found that the fluorescent absorption coefficient can be represented by a formula of the form $\gamma'_{\rho} = \alpha \ \lambda^n \ Z^m$ where <u>m</u> and <u>n</u> are constants only over small ranges of Z and λ . Different values have to be assigned to <u>m</u> and <u>n</u> if we are to cover all the elements over a large wavelength range. The variations in the values of the exponents <u>m</u> and <u>n</u> are discussed in the light of the results of several investigators.

An empirical formula, which gives excellent values of the K absorption ratios (jump ratios), for most of the elements, is also deduced. It shows that they vary inversely as the square root of the atomic number.

Lastly, some approximate scattering mass absorption coefficients are deduced, and plotted to show their variation with atomic number and wavelength.

CONTENTS.

PART 1

THE PRODUCTION OF THE MONOCHROMATIC X-RAY BEAMS.

| Sec. 3 | 1.10 | | | | 9 or 10 - 1 | page |
|--------|---------|---------------------|---------------------|-------------|-------------|-------|
| 1.1. | Introd | uction | Х. : х <u>а</u> сер | | | l |
| 1.2. | The Fi | ne P owder F | Focussing M | onochromato | r | 4 |
| | (a) | Theory of | the Instru | nent | | 4 |
| | · · (b) | Practical | design of | the Monochr | omator | 6 |
| a - 1 | (e) | Choice of | Wavelength | S | 14 - A | 8 |
| 1,3, | Rotati | ng Anode X- | ray Tube. | and to a | 1.1.840 | 14 |
| | (a) | Introducti | on | | | 14 |
| | · · (b) | Descriptio | on of the Re | otating Ano | de | а |
| 8.88 | 1. | X-ray tube | | | 4 | 14 |
| 1.4. | The Co | llimating S | lit System | S | and and a | 18 |

PART 2

DESIGN OF A GEIGER-MULLER COUNTING SYSTEM FOR MEASURING THE INTENSITIES OF THE MONOCHROMATIC

BEAM

| 2.1. | Introduction | 20 |
|------|----------------------------------|----|
| 2.2. | X-ray Counter tube | 21 |
| | (a) Choice of Counter tube | 21 |
| | (b) Construction of Counter tube | 22 |
| | (c) Filling procedure | 24 |
| 2.3. | The Quenching Circuit | 26 |
| 2.4. | The Counting Circuit | 29 |
| | (a) The Scale of Two Circuit | 29 |
| | (b) The Scale of Ten Circuit | 30 |
| | (c) The complete Counting Unit | 31 |

| | Page |
|--|------|
| 2.5. Power Supplies. | 33 |
| (a) The H.T. Power Supply | 33 |
| (b) The E.H.T.Power Supply | 34 |
| 2.6. Setting up Procedure, and General Test of | |
| the Counting system | 35 |

PART 3.

THE ABSORPTION OF X-RAYS BY THIN

METAL FOILS.

| 3.1. | Introduction | 42 |
|------|---|----------|
| 3.2. | Preparation of Foils. | 45 |
| | (a) Rolling of Foils | 45 |
| | (b) Measurement of Foil thickness. | 46 |
| | (c) Mounting of Foils | 46 |
| 3,3, | Method of measuring 1/1 and correction | 1'5 1 |
| | factor. | 47 |
| | (a) Ideal counters | 47 |
| | (b) Correction for Background count. | 50 |
| | (c) Correction for Counting losses | 53 |
| | (d) Measurement of $(\frac{K\gamma}{T})$ | 59 |
| 3.4. | Absorption of Cu Ka, Radiation by thin foils | 62 |
| | (a) Preliminary work | 62 |
| | (b) Experimental Technique | 65 |
| | (c) Results | 67 |
| 3.5. | Absorption of Co K c, radiation by thin foils | 78 |
| 5 | (a) Preliminary work | 78 |
| | (b) Results | 79 |
| 3.6. | Comparison of the two measured mass absorpt- | |
| | ion coefficients $(\frac{\mu}{\rho})$ and $(\frac{\mu}{\rho})'$ | 90 |
| 3.7. | Absorption of Chromium radiation by thin | |
| | metel foils | 93 |

| | pa | ge |
|----|---|----|
| (8 | a) Preliminary work 93 | 3 |
| (1 |) Measurement of mass absorption coefficients | |
| | with beams containing more than one wave- | |
| | length 94 | 1 |
| ((| e) Counting Loss Corrections 97 | |
| (d | l) Results 99 | - |
| | | |

PART 4.

| | coefficients with values obtained by other | |
|------|---|---|
| | investigators. | 1 |
| 4.2 | The atomic absorption coefficients | į |
| 4.3 | (a) Variation of the atomic absorption | |
| | coefficient with atomic number | |
| | (b) Comparison with the results of other | |
| | workers | |
| 4.4. | (a) Variation of the atomic absorption coeff- | • |
| | icient with wavelength | |
| | (b) Comparison with the results of other | |
| | investigators | |
| 4.5. | (a) Empirical Absorption Formulae deduced fro | m |
| | the results | |
| | (b) The K-absorption jump ratios as given by | |
| | the present empirical formulae | |
| 4.6. | Approximate mass scattering coefficients | |
| | deduced from the empirical absorption | |
| | formulae and known values of the total mass | |
| | absorption coefficients. | |
| | Conclusion | |
| | References | |

GENERAL INTRODUCTION

The principal phenomena that have been observed when a beam of X-rays impinges upon matter are the production of

(a) Photo-electrons and fluorescent characteristic X-rays.

(b) Modified and unmodified scattered X-rays. Each process is measured by the fraction of the energy which it removes from a beam of X-rays of unit cross section as it traverses unit mass of material, and is called the mass absorption coefficient. The energy removed by the photoelectric effect gives rise to the fluorescent mass absorption coefficient, while that scattered by the material gives the scattering mass absorption coefficient. The total amount of energy removed from the beam is due to both processes, and yields the total mass absorption coefficient.

A considerable amount of work has been carried out on these coefficients over the past years, and they have been found to depend on the wavelength of the radiation and the atomic number of the material irradiated.

In 1912, before definite wavelengths were assigned to X-rays, Owen⁽¹⁾ pointed out that the total mass absorption coefficient was approximately inversely proportional to the fifth power of the atomic weight of the radiator. After the work of Moseley in 1913 showing the characteristic radiation of an element to be inversely proportional to the square of the atomic weight, the result indicated that the absorption coefficient was approximately proportional to the $\frac{5}{2}$ th power of the wavelength of the radiation employed.

Further experiment⁽²⁾ gave the relation, the fluorescent mass absorption coefficient $\mathcal{V}_{\mu} = \alpha \lambda^3$ as a more accurate

representation of the observed results, with the stipulation that the value of the constant • changes suddenly at the critical absorption wavelengths. The total mass absorption coefficient is then given by the above expression plus a small term to represent the scattering of the X-rays.

Most of the data which had accumulated on absorption coefficients up to 1926, however, covered rather short wavelengths (< 0.7 kX units) where the scattering of the X-rays plays a prominent part in the whole absorption process and thus made it rather difficult to decide from total absorption coefficients alone, how the fluorescent coefficient varied with the wavelength.

During this time some direct measurements of the scattering coefficients were carried out by Hewlett⁽³⁾ Statz⁽⁴⁾ and Mertz⁽⁵⁾ by collecting the scattered radiation in an ionisation chamber surrounding the scatterer, but the results covered only the light elements at short wavelengths, and the comparatively large value and uncertainty of the corrections for internal absorption in the specimens themselves made them rather unreliable.

At longer wavelengths (> 1.0 kX units) the mass scattering coefficient (%) becomes negligible in comparison with (%) except for elements of lower atomic number than Carbon, and the total mass absorption coefficient can be taken as approximately equal to the fluorescent coefficient. Measurements at these wavelengths should therefore give more accurate information about the variation of $(\frac{\gamma}{\rho})$ with wavelength.

In 1926 the total mass absorption coefficients of a number of elements from Carbon to Uranium for homogeneous rays from $\lambda = 0.7$ to 1.933 kX units and for filtered general rays from 1.93 to 4.0 kX units were measured by Allen⁽⁴⁾ and he concluded that nowhere does λ^3 over a long range

accurately represent the data. In general, the values of the exponent which best fitted the results were a high value 2.92 and a low value 2.6.

Since then a considerable amount of work has been done in an attempt to find the best value of the exponent for different metals and gases over a large range of wavelengths. The values obtained all range between 2.5 and 3.0.

The variation of the fluorescent absorption coefficient with atomic number has also been investigated, but not so extensively as the dependence on the wavelength. In this case, the results indicate values ranging from 4.0 to 4.6.

In view of this lack of agreement between different workers as to the best values for the exponents of the wavelength and the atomic number in empirical relations for the mass absorption coefficients it was decided that some measurements carried out with pure monochromatic beams might provide useful data which would throw further light on to the problem.

A Geiger counter method is used for the measurement of beam intensity, instead of the usual ionisation chamber or photographic film methods, in an attempt to eliminate some of the experimental difficulties associated with the measurement of X-ray absorption coefficients.

PART 1.

THE PRODUCTION OF THE MONOCHROMATIC X-RAY BEAMS.

1.1. INTRODUCTION.

The radiation emitted by an ordinary X-ray tube consists of a series of characteristic emission lines, superimposed on a continuous background of white radiation. Thus, in order to produce a pure monochromatic beam, we must select one of the characteristic lines and successfully separate it from the other wavelengths emitted by the tube.

This is usually accomplished by selective reflection of the desired wavelength by means of a crystal - a certain wavelength λ being reflected if the angle of incidence θ of the primary beam on to a crystal plane is given by the Bragg equation

$n\lambda = 2 d \sin \theta$

where n is the order of reflection and d is the spacing of the crystal planes.

Nearly all monochromators work on this principle, but differ in detail according to the size, shape and number of crystals employed.

In the simplest case, a fairly large single crystal is used as a reflector, and very careful alignment of the crystal at the correct angle in the X-ray beam is necessary. Further, we see from fig (1.1) that only a very narrow portion of the divergent beam from the X-ray tube is incident at the correct angle θ to give rise to a reflected ray of wavelength λ . All the incident rays of this wavelength which lie outside the narrow region are not reflected and so a large portion of the available intensity is wasted.

Monochromators were then designed which would reflect all the rays of a particular wavelength in a divergent beam to a certain point, where the intensity would thus be greatly enhanced.

First, Johann^(*) developed a monochromator using the reflections from the surface planes of a bent mica crystal. The mica is bent to a radius R and irradiated with X-rays from a source situated on the circumference of a circle of radius $\frac{1}{2}$ R as shown in fig (1.2). We see that in this case a much larger portion of the incident beam strikes the crystal at the correct angle θ for the wavelength λ to be reflected, and that all the reflected rays from different portions of the crystal converge approximately to a point F on the circumference of the circle, where the energy is thus concentrated.

Du Mond and Kirkpatrick⁽⁸⁾ then showed that if a crystal is both cut and bent, perfect focussing could be obtained. The crystal is bent as before until the crystal planes have a radius R, and then the surface is cut to a radius $\frac{1}{2}$ R. This focussing principle is shown in fig (1.3).

Since the technical difficulties encountered in bending and grinding crystals for these monochromators were very great, Du Mond and Kirkpatrick designed another type of instrument, where the reflecting surface is built along the arc of a circle by means of a large number of tiny individually orientated single crystals. The process involves an exceedingly labourious method of setting up the single crystals, each one of which has to be prepared individually.

In order to overcome this difficulty Professor E. A Owen suggested using a very fine crystalline powder as the reflector in a monochromator. The large number of tiny crystals involved ensures the presence of a number of correctly orientated crystal planes to reflect the beam, without any difficult alignment of crystals being necessary. Further it would not be required to prepare single crystals and all difficult grinding and bending of crystals would be avoided.

A satisfactory monochromator of this type was previously designed and developed in the laboratory.



Fig 1:3 BENT AND CUT CRYSTAL.

4

(a) Theory of the Instrument.

In principle, a fine crystalline powder is arranged over a small arc of a circle and irradiated with X-rays from a point source situated on the circumference of the circle, diametrically opposite the powder as shown in fig (1.4).

Assuming the tiny crystals of the powder to be orientated entirely at random, there will be a large number of crystal planes in correct position relative to the incident beam to reflect rays in certain directions.

Let us consider only the rays reflected in the plane of the circle. All the rays of a particular wavelength will be deviated by crystal planes of spacing d through an angle 2 θ given by the equation

 $\lambda = 2 d \sin \theta$

and we note that, by geometry, if $(\pi - 2\theta)$ lies in the range $0 - \frac{\pi}{2}$, the reflected rays will converge to points such as P and P' as shown in fig (1.4). Hence, if λ is one of the characteristic wavelengths present in the primary beam, the monochromator forms (at P and P') two sources of monochromatic characteristic X-rays.

We may note here that if another set of crystal planes of spacing, say, d, also reflect the wavelength λ at an angle θ given by

$$\lambda = 2 d_sin \theta_c$$

such that $(\pi - 2\theta)$ lies between 0 and $\frac{\pi}{2}$ another two

1.2.

sources P P; of monochromatic rays of this wavelength will be formed.

Other characteristic wavelengths present in the primary beam will be reflected to other pairs of points symmetrically placed on the circumference of the circle.

The white radiation which contains a continuous range of wavelengths will be scattered more or less uniformly over the whole circle.

We see that, in effect, the primary beam is fanned out into a spectrum by the crystalline powder, and the degree of monochromatisation possible depends on the ability of the instrument to separate two very close wavelengths. In fig (1.5) the length of the arc PP' = s is given by

$$s = 4r(\pi - 2\theta)$$

where r is the radius of the circle and θ is given by

From these

$$\delta s = 8 r \delta \theta$$
 and $\delta \lambda = 2 d \cos \theta \delta \theta$

Hence

$$\frac{\delta s}{\delta \lambda} = \frac{4 r}{d \cos \theta}$$

The separation of the focal points P for wavelengths λ and $\lambda+\delta\lambda$ is then

$$D = \frac{1}{2} \delta s = \left(\frac{2 r}{d \cos \theta} \right) \delta \lambda^{-1}$$
(1.1)

If Copper radiation is resolved in a monochromator of radius 5 cms, containing a silver reflector, the equation gives a separation D = 2.5 mms for the K α_1 and K α_2 wavelengths.







Fig 1.5

We see therefore that the instrument is well capable of resolving the $K \alpha_1 \alpha_2$ doublets and will produce beams of pure $K \alpha_1$ or $K \alpha_2$ wavelengths.

It is seen from the equation (1.1) that the separation D increases as θ increases, so that the resolving power of the instrument is better the smaller we make the arc PP'.

In practice, a powder is chosen as a reflector if it possesses a set of crystal planes which will give a good reflection of the required wavelength at (π -20) approximately 30°.

(b) Practical design of the Monochromator.

In the practical

form of the instrument a cylindrical drum is used, and the reflected beams intersect in small ares symmetrically situated around the pin-hole through which the incident beam enters. Two slits are cut in the cylinder to allow the required radiation to escape - the cylinder shielding all the other wavelengths. The two corresponding slits then become line sources of divergent monochromatic X-rays.

The drum is approximately 10 cms in diameter, and consists of a strip of brass 2 mms thick and 4 cms wide, bent round two steel former rings. There are three equally spaced slots cut in the cylinder - one of them being covered with the reflecting powder and irradiated with X-rays entering the cylinder through a pin-hole slit system fixed diametrically opposite the centre of the slot.



Fig 1.6 Photograph of the Monochromator.

The other two slots are covered with lead sheets fixed firmly in position. Each lead sheet contains a narrow vertical slit (1 cm by 2 mm) cut in exactly the right position to allow the required wavelength to escape from the instrument. The reflecting surface consists of a thin layer of very fine crystalline powder spread evenly over a piece of pliable cardboard smeared with a thin coat of adhesive and held firmly in position over the slot.

The monochromator stands on a brass table capable of being raised or lowered so as to bring the entrance pinhole in line with the primary beam from the X-ray tube. The table has a raised circular portion of the same radius as the inner radius of the monochromator, so that the latter fits firmly on the table - a small lug engaging in a hole in the lower former ring to lock it in position.

In this way, it is possible to pick up the monochromator and replace it in exactly the same position on the table.

The table is rotated until the most intense portion of the primary X-ray beam passes through the pin-hole and irradiates the fine powder in the most efficient manner.

Fig (1.6) shows a photograph of the monochromator mounted in position in front of the X-ray tube window. The lead shields which are placed round the instrument to cut down stray radiation have been removed.

(c) Choice of wavelengths.

We are limited in our choice of wavelengths for the monochromatic beams by two main factors.

- Only the characteristic wavelengths of elements which will form suitable targets for the X-ray tube are available.
- (2) Suitable reflectors of these wavelengths must be found.

The metals most generally used as targets, together with the K_{α_1} , K_{α_2} wavelengths emitted are given in table (1.1) below. Wavelengths longer than the K_{α} lines of Chromium are very easily absorbed by the X-ray tube window and in air,

TABLE 1.1

| | 77 7 | Ka, | Kαz | | |
|----|-------------|----------|----------|--|--|
| 2 | Element | kX units | kX units | | |
| 24 | Chromium | 2,2850 | 2,2889 | | |
| 26 | Iron | 1.9321 | 1,9360 | | |
| 27 | Cobalt | 1.7853 | 1.7892 | | |
| 28 | Nickel | 1.6545 | 1.6583 | | |
| 29 | Copper | 1.5374 | 1.5412 | | |
| 42 | Molybdenum | 0.70783 | 0.71280 | | |
| 47 | Silver | 0,55828 | 0.56267 | | |

while wavelengths shorter than the $K\alpha$ lines of Silver require very high voltages to produce, and are so penetrating that it is difficult to limit them by screens.

It is seen from the table that there are no suitable elements between Copper and Molybdenum, which leave a large gap in the wavelength range covered by these targets.

It was decided in the first instance, to use Chromium, Cobalt, Copper and Molybdenum as target elements, and to produce monochromatic beams of their $K\alpha$, wavelengths.

A search for suitable reflectors of these wavelengths was carried out with an ordinary focussing camera and a stationary anode X-ray tube fitted with these targets.

A film taken with a particular powder specimen would show at once whether it was a suitable reflector or not. A good reflector would be indicated by a film showing a strong, sharp line situated about 4 cms from its centre, with the $\alpha_1 \alpha_2$ doublet clearly resolved Further the line should be of uniform density, because any tendency to be "spotty" would point to a non-uniform monochromatic beam.

The monochromator was originally designed to give out a beam of Cu K α_i radiation, the reflector being fine silver powder with the monochromator slits accurately aligned to allow the K α_i beam reflected by the $Q^2 = 27$ planes of silver to leave the instrument. It was found by calculation that the Co K α_i radiation is reflected to almost the same position by the $Q^2 = 20$ planes of silver. An exposure was taken and the line found to be quite strong and the doublet clearly resolved. Hence, simply by interchanging Copper and Cobalt targets we can change the wavelength of the Monochromatic beam from Cu K α_i to Co K α_i without changing the reflector or altering the slit positions.

Similarly, it was found that the $Q^2 = 12$ planes of Aluminium or the $Q^2 = 8$ planes of Tantalum would reflect the K α_i radiation from a Chromium target to the same slit positions. Hence, in order to produce a beam of Cr K α_i radiation, all we need do is insert a chromium plated target in the X-ray tube and change the reflecting powder

| Radiation | Wavelength kX | Reflector | Structure | Parameter kX | Reflecting Planes | Q2 | Log 1/Q | Log 7/2a | Log sin0 | sin 0 | $\frac{\pi}{2} - \theta$ | s cms |
|-----------|------------------|-----------|-----------|-----------------|----------------------|----|---------|----------|----------|--------|--------------------------|----------|
| Cu Ka | 1.537395 | Silver | F.C.C | 4.0779 | 115. 333 | 27 | 1.28432 | 1.2753 | 1.9910 | 0.9795 | 0.2026 | 4.167 |
| Cu Ka, | 1.541232 | Silver | F.C.C | 4.0779 | 115. 333 | 27 | 1.28432 | 1.2764 | 1.9921 | 0.9819 | 0.1906 | 3.919 |
| Co Ka | 1.78529 | Silver | F.C.C | 4.0779 | 024 | 20 | 1.34948 | 1.3402 | 1.9907 | 0.9788 | 0.2060 | 4.236 |
| Co Kaz | 1.78919 | Silver | F.C.C | 4.0779 | 024 | 20 | 1.34948 | 1.3411 | 1.9916 | 0.9809 | 0.1958 | 4.025 |
| Cr Ka, | 2.28503 | Aluminium | F.C.C | 4.0414 | 222 | 12 | 1.46041 | 1.4513 | 1.9909 | 0.9792 | 0.2031 | 4.177 |
| Cr Kaz | 2.28891 | Aluminium | F.C.C | 4.0414 | 888 | 12 | 1.46041 | 1.4520 | 1.9916 | 0.9809 | 0.1958 | 4.025 |
| Cr Ka | 2.28503 | Tantalum | B.C.C | 3.2959 | 022 | 8 | 1.54846 | 1.5399 | 1,9914 | 0.9804 | 0.1983 | 4.078 |
| Cr Kaz | 2.28891 | Tantalum | B.C.C | 3.2959 | 022 | 8 | 1.54846 | 1.5406 | 1.9921 | 0.9819 | 0.1906 | 3.919 |

TABLE 1.2 Details of the Reflectors used in the Monochromator.



Fig 1.7 Relative positions of the Ka, Ka, doublets.

Scale : $l cm \equiv l mm$.

to Aluminium or Tantalum. Again no readjustment of the slit positions is necessary.

The monochromator can thus be adjusted very quickly to give monochromatic beams of wavelengths Cu K $\alpha_{,}$, Co K $\alpha_{,}$ and Cr K $\alpha_{,}$. Table (1.2) gives the relevant details about the reflectors, and from the diagram showing the relative positions of the three doublets (fig. 1.7) it is seen how a well placed slit will transmit any one of the K $\alpha_{,}$ radiations without readjustment in position, while the K $\alpha_{,}$ radiation is completely screened in each case.

All attempts to produce monochromatic beams of wavelengths shorter than the Cu K α_i wavelength were unsuccessful.

First a search for a suitable reflector of Mo K α_1 radiation was carried out. The target was prepared by brazing a thin layer of brass on to a molybdenum sheet, which could then be easily soldered on to the end of a brass X-ray tube target holder. Powdered specimens of Diamond, Carborundum, Silver, Copper, Aluminium and Iron were examined, but no strong lines were observed with any of these specimens. It was concluded that the wavelength Mo K α_1 is too short to give strong reflections in the angular range required by the monochromator.

Secondly, a search for a suitable reflector of Pt $L\alpha_1$ radiation was carried out. The target in this case was prepared by soldering a thin platinum foil on to the surface of a copper target. Powdered specimens of Molybdenum, Copper, Iron, and Magnesium were examined, but no lines were observed. We conclude that the lines of the L-series wavelengths are relatively weak and cannot be distinguished from the background radiation on the films. Lastly, the possibility of using Ge K_{α_i} radiation to bridge the wavelength gap between Copper and Molybdenum was investigated.

A stationary anode target was prepared by allowing a small lump of Germanium to melt and run into a thin layer on the surface of an ordinary copper target. Specimens of Iron, Tantalum, Molybdemum and Silicon were examined. No lines were observed with the Iron specimen, due to the very heavy background produced by fluorescent X-rays excited in the iron by the Germanium radiation.

The other specimens gave Copper and Germanium lines, but the latter were too weak to use as monochromatic beams. It was concluded that , in this case, the target was an alloy of Copper and Germanium - both radiations being produced.

The Cu K α , radiation was not absorbed heavily by the target (Mass absorption coefficients Ge = 69.4; Cu = 52.7 at Cu K α , wavelength) and the X-ray tube gave out a reasonably strong beam of Cu K α , radiation. On the other hand, the Ge K α , radiation was absorbed rather heavily by the target material (Mass absorption coefficient Cu = 238 at Ge K α , wavelength) and so the Ge K α , output is heavily weakened, giving weak lines.

An attempt was then made to produce a Germanium target by melting on to iron instead of a copper target, but it was found impossible to get a thin layer of Germanium to adhere to it. Since a cylindrical target would have to be made from the material, it was thought impractical to use Germanium.

We can say therefore, that the wavelength range of the monochromator is rather limited, the lower limit being set by the lack of suitable target materials and

reflectors, while the upper limit is set by the excessive absorption in air of the long wavelengths, while the white radiation comes through practically undiminished in intensity.

Over the suitable range, however, the instrument can produce very pure monochromatic beams because of its good resolving power. Furthermore, two beams of exactly the same wavelength are produced from the same source of radiation so that any intensity fluctuations will be transmitted to both beams simultaneously. Their intensities will thus be at any instant in a constant ratio to each other, so that if one beam is used for experiment, the intensities obtained can be corrected for input fluctuations by comparison with the other beam used as a standard of reference.



THE ROTATING ANODE X-RAY TUBE.

(a) Introduction.

1.3

In a stationary anode X-ray tube, the electron stream is directed against a fixed area on the target called the focal spot, and the rating of the tube is limited by the ability of the target to dissipate the heat generated before the temperature of the bombarded area reaches the melting point of the metal. Any attempt to increase the intensity of the radiation from such a tube, by bombarding a smaller area with more energy soon results in the melting and destruction of the target.

A rotating anode X-ray tube, however, has a much higher rating because the fine focal spot is effectively increased into a thin ribbon of metal by the rotation of the target, so that relatively cool metal is brought continuously before the electron stream, and an intense beam can be produced without damage to the target.

The tube used for this work was designed by Professor E.A.Owen, and is shown diagramatically in fig (1.8).

(b) Description of the Rotating Anode X-ray tube.

The cathode, A,

consists of an Aluminium rod (approximately 1.3 cms diameter and 35 cms long) sheathed in a brass tube. It passes into the water-cooled cathode end, B, of the X-ray tube, and is held in position by the nut, C, fitting into the inner tube of the water jacket, and the collar, D, which presses against its lower face, E.



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The free end, F, of the rod is turned down on a lathe so that its radius of curvature is about 5 cms and a small lip (2mms) of brass tube left to assist in focussing the electron beam on to the target. This end of the rod becomes pitted when the tube is working, and has to be re-shaped occasionally.

The anode end of the X-ray tube is separated from the high voltage cathode end by the insulating porcelain cylinder, H, (20 cms long by 5.5 cms internal diameter). This cylinder is attached to the two parts of the tube by built up union muts, I, which press the ground flanges of the porcelain against good quality rubber rings, J, resting in the end pieces, thus making vacuum tight joints.

The anode end of the tube contains the rotating target, K, and is directly earthed. A small rectangular hole, W, cut in the casing, and covered with a thin sheet of mica, serves as an exit window for the X-radiation coming from the target face. A saddle tank, L, round the tube serves to cool the region surrounding the cathode, F, and also supports the electric motor, M, which rotates the target through a vacuum tight seal - the whole assembly being made up as one compact unit, N, which fits on to the main X-ray tube. This unit is shown in greater detail in fig (1.9).

The hollow cylindrical target, A, screws firmly on to the end of a long spindle, S, a greased rubber washer,W, making the joint vacuum tight. This spindle passes out of the X-ray tube through the rotating seal, enclosed in the housing, H, and is held in position by a spaced pair of ball races, B B, being then connected through a train of gear wheels, Q, to the electric motor, which rotates it at 300 revs/min. The seal is made by the perfectly flat surface of the fixed carbon ring, C, always remaining in complete all round contact with the perfectly flat surface of the steel ring, R, which rotates with the spindle. This steel ring fits tightly on a thick neoprene washer, N, held on a brass bush soldered on the spindle, while the carbon ring is fixed to the flexible bellows, F, soldered into a brass block, D. This screws into the housing, H, a rubber washer, M, making the joint vacuum tight.

The spring, P, coiled round the bellows pushes the carbon surface against the ring, while the flexible bellows allows the carbon to follow any irregular motion of the steel ring, and thus always remain in complete contact, making a good seal.

Contact pressure between the two surfaces can be varied by altering the spacing of the ball races. The seal is lubricated occasionally with a small amount of high vacuum oil to ensure smooth running and no undue wear of the surfaces. A small hole, 0, cut in the housing, approximately opposite the seal allows this to be done without dismantling the assembly.

A water chamber, E, fitted with Gaco washers, V, to stop leakages, fits on the upper end of the rotating shaft. Water enters this chamber through the tube, L, and is then carried down the shaft through the fixed narrow tubing, T, and directed against that portion of the target cylinder bombarded by the electron stream. The water then flows out through the space between the fixed tube and the rotating shaft, to the lower half of the chamber, C, to be drained away through the copper tube, U.

The whole rotating anode assembly fits on the side tube, G, which projects from the anode end of the main

X-ray tube. This side-tube has a threaded collar, I, which is recessed to take the flange, J, soldered on the seal housing. The flange rests on a greased rubber washer, and is clamped tightly in place by the screwed ring, K, to make the joint vacuum tight.

The side-tube, G, is not set exactly at right angles to the main X-ray tube, but is inclined about 8° from this position, so that the electron beam does not fall perpendicularly on to the target face. In this way, a horizontal beam of X-rays emerges from the tube when it is mounted in a vertical position.

The tube is fixed on an angle-iron framework by means of the brass plate, P, fig (1.8) soldered just below the lower screw joint, and which fits into the trough formed by the horizontal angle bars of the stand.

The voltage required by the tube is supplied by a high voltage transformer, one end of the secondary winding being connected to the anode and the other earthed through a milliammeter, which registers the tube current. The transformer is supplied through a small auto-transformer so that the voltage can be gradually raised to the working potential as the tube vacuum improves. A point and plane spark gap (4 cms) connected in parallel with the tube serves as a protection against the voltage becoming too high.

The X-ray tube is evacuated by an oil diffusion pump backed by a two stage rotary pump, the pressure being controlled by adjustment of the taps in the connecting glass tubes.

THE COLLIMATING SLIT SYSTEMS

These limit the divergence of the X-ray beams leaving the monochromator, in order to produce narrow, well defined beams, suitable for absorption measurements with thin foils.

We have two such collimating systems - one for each beam, and each consists of adjustable slits mounted on a stand as shown in fig (1.10).

The stand is a horizontal steel bar, supported at one end by a short vertical pillar mounted on a heavy base plate. The bar has one edge uppermost and can be swivelled round the pillar to any required position and clamped in place.

When mounted with the pillar directly under the monochromator slit, the steel bar can be swivelled into the beam so that its upper edge marks the beam direction, and it acts as a guide-way along which the slits can be moved on V-shaped supports. These supports are fitted with fine vertical and transverse movements for final positioning of the slits in the beam, and can be clamped on the guide-bar in any desired position. The Geiger counter tube, used to measure the beam intensity, is also mounted on the same steel bar in a similar manner.

The whole arrangement is set up and adjusted as follows :-

 First of all the counter only, is mounted on the guide-way, being placed at a reasonable distance from the monochromator slit, and the guide-way swivelled round until maximum response is obtained. It is then clamped in position.

18

1.4.

(2) A slit is then placed on the guide-bar, and after adjustment to a convenient size, is set, by means of the fine vertical and transverse movements until maximum response is again obtained in the counter. The slit is then in line with the monochromator slit, and the counter window, and so allows a narrow portion of the divergent monochromatic beam to enter the Geiger tube. This is sufficient collimation for the beam used as a standard of reference.

In the case of the other divergent beam, which is used for experiment, further collimation is necessary, and a second slit is placed on the guide-way, and adjusted for maximum response. The monochromator slit, both collimating slits, and the counter are then in line, so forming a narrow and nearly parallel beam of monochromatic X-rays suitable for absorption measurements.

In the case of this experimental beam, a brass holder, on which the absorbing foils can be mounted, is capable of being placed on the guide-bar, between the two slits, or right up against the counter window as required.

(3)

PART 2.

DESIGN OF A GEIGER - MULLER COUNTING SYSTEM FOR MEASURING THE INTENSITIES OF THE MONOCHROMATIC BEAMS.

2.1. INTRODUCTION.

For many years, photographic films and ionization chambers have been widely used for all kinds of intensity measurements with X-rays, each method having several distinct advantages over the other, depending on the problem under consideration.

In recent times increasing use is being made of the Geiger counter, in place of the ionization chamber, although the electronic circuit necessary for recording the arrival of X-ray quanta into the counter tube is far more complicated. The sensitivity, however, is higher, and the method has lost none of the advantages the ionization chamber has over the photographic film.

In the present investigation, the main advantage of the Geiger counter over the photographic film is that a comparatively accurate intensity measurement can be made in a few minutes, whereas the photographic film would require a much longer exposure time (3 hours) and would then have to be carefully processed and microphotometered to obtain the beam intensity.

With a Geiger counter all these operations are replaced by a single counting process.

The component parts of the complete Geiger - Muller counting system designed for this work will now be discussed in detail.
THE X-RAY COUNTER TUBE.

(a) Choice of counter tube.

A Geiger tube detects X-rays by virtue of the charged particles released within its active volume. Up to 1948, most tubes were designed to receive the X-ray beam on their cathode walls with negligible gas absorption, with the result that their efficiencies were rather low, since only a relatively small fraction of the photo-electrons released from the walls reached the accelerating field of the tube.

On the other hand, if the photo-electrons are produced in the gaseous content of the tube, they will almost certainly produce a discharge, and the efficiency should be considerably increased.

The type of tube designed by H. Friedman approaches this ideal very closely, and it was decided to construct similarly shaped tubes for this work.

The tube consists essentially of a long cylinder with a thin window at one end to receive the X-ray beam, with the anode wire running co-axially along the cylinder. The beam can thus travel the whole length of the tube more or less parallel to the central wire and very near to it. It has therefore the best possible chance of being wholly absorbed in the gas and thus produce photo-electrons in the sensitive volume to initiate the discharge. Moreover, the end of the anode wire can be brought quite near the window so that there is very little volume of gas where the beam can be absorbed before it reaches the sensitive part of the counter. The end of the wire carries a glass bead to

2.2





diminish the high field strength which would occur at this point if left free.

For this work, it was decided to use argon as the gas in the tube, because it strongly absorbs the characteristic radiations of Copper, Iron, Cobalt and Chromium - typical radiations that can be produced by means of the present monochromator.

Further, a small amount of organic vapour (methylene bromide) is added to the gas in order to reduce the number of charged particles available for maintaining a discharge, so that each discharge rapidly quenches itself, and the dead time of the counter is appreciably shortened.

(b) Construction of counter tube. (see fig. 2.1.)

A piece of

drawn brass tubing, A, about 15 cms long, 1 cm inside diameter, and which is relatively free from flaws and blemishes, is chosen. The inside surface is then cleaned with successive grades of emery paper until all the flaws are removed, and then finally polished.

A brass flange, B, is then soldered on to one end of the tube to provide a fairly large surface area to hold a mica window firmly in position. The window (.02 mms thick) is glued on to the flange and a brass ring fixed over it. The ring is then clamped tightly in place by means of three toolmakers' clamps, which are left in position until the glue is thoroughly dry.

A brass end piece, C, fits tightly into the other end

of the tube. This end piece contains a glass capillary tube, D, which supports the anode wire, W, and at the same time insulates it from the grounded cathode.

Originally, steel wire was used for the anode, prepared as follows:-

Steel wire, 0.26 mms diameter, was heated by a small flame while hanging vertically under the pull of a weight the flame being moved slowly along it until it softened and gradually straightened. A suitable length of it was then chosen, thoroughly cleaned and polished, and a glass bead, E, formed at one end. This was most easily accomplished by forming the bead (2mms diameter) on a flat metal surface first, heating it until soft, and quickly pressing the end of the wire into it - the bead being finally rounded off in a gas flame.

Steel wire was found to deteriorate rapidly under the action of the quenching vapour and eventually nickel wire was used instead.

Some difficulty was experienced in keeping the wire central in the tube, due to a tendency to sag under its own weight and that of the glass bead at its free end. This was overcome by giving the anode wire a slight upward curve to counteract the sag, and mounting the counter in one particular position such that the wire was quite central in the tube. Before the counter was assembled, the inside surface of the tube and the anode wire were thoroughly cleaned with pure alcohol and surgical gauze to remove all traces of dust or fibre which might cause spurious discharges in the counter. Too much attention cannot be paid to this point.

The counter is made gas tight by going over all the joints, first with ordinary glue and then with picein wax



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 $\langle I_{i}, \gamma \rangle_{i}$

when the former is thoroughly dry. Ordinary glue was found to be better than any other sealing compound for this purpose because it was not easily attacked by thev organic quenching vapour. The counter would thus last for a long period without developing leaks.

Finally, it is fitted with a gas reservoir, R, as shown in fig (2.1) so that it can contain a reasonable amount of gas and quenching vapour.

(c) Filling Procedure.

A very simple filling system, the essentials of which are shown in fig (2.2) is adequate for the counters described. In order to obtain the correct pressure and ratio of gas to vapour in the counters, the following procedure is carried out.

(1) First of all we evacuate all parts of the system, including the counters, and make sure that there is no leak anywhere. Particular care is taken when checking the counters because even a very small leak would alter the gaseous contents of the tubes, and destroy their plateaux in a few hours.

(2) The reservoir containing the methylene bromide quenching vapour is then evacuated for a few minutes to remove all traces of air. The tap is then closed and the reservoir contains only quenching liquid and vapour.

(3) Evacuation of the system is continued for a while, and then, with the exception of the liquid reservoir, flushed with argon from the cylinder, by admitting gas to a few cms pressure, as indicated on the manometer. The cylinder valve is then closed and the system re-evacuated. (4) The gas reservoir is then filled to atmospheric . pressure with argon from the cylinder and the stop-cock closed. This gas is then available for flushing and filling the counter tubes when required, the reservoir being refilled from the argon cylinder when necessary.

(5) To fill the counters, the system, exclusive of the gas and liquid reservoirs, is again evacuated, and left on the high vacuum oil diffusion pump for about an hour. The stop-cock to the pump is then closed, and the quenching vapour admitted to the counter tubes to a pressure of 1 cm, as read on the mercury manometer.

(6) Argon is then admitted from the gas reservoir until the total pressure is 15 cms of mercury, and the stopcocks on the individual counter tubes closed. It is also advisable to clip the rubber tube connections to the counters so that only a small portion is included in the counter volume. This is because methylene bromide slowly attacks the tubing which would cause the composition of the gas mixture to change with time, thereby appreciably shortening the life of the counters.

After filling, they are left for several hours to allow the gas/vapour mixture to come to equilibrium.

(7) Lastly, the counters are tested for starting voltages and plateaux as described in section 2.6 of this thesis.



FIG 2.3 BASIC QUENCHING CIRCUIT.

THE QUENCHING CIRCUIT.

This circuit acts so as to reduce quickly, the voltage across the Geiger tube, to a value below the threshold potential, when a count takes place. It then holds the counter wire at this voltage for a time interval longer than the collection time of the positive ions, and then quickly restores the potential back to its normal value, whence the counter is again sensitive, and ready to receive the next pulse. In this way the dead time of the counter is increased, but is defined accurately by the circuit, and is therefore constant in value, so that reliable corrections for lost counts can be made. Another advantage is that spurious counts, which may arise during the interval are suppressed.

The basic circuit is a capacitatively coupled multivibrator, triggered by a pulse from the counter ; the negative square waveform so generated being fed back to the counter, so as to lower its potential below the threshold value for a determined period of time. It is essentially the circuit due to Cooke-Yarborough, Florida and Davey⁽¹⁰⁾ and the basic circuit is shown in fig (2.3).

When a burst of ionisation occurs in the counter, we have a fall in the potential of the anode wire. This is transmitted through the condenser, C, to the grid of the valve, V_3 which is normally conducting since the grid is held near earth potential by the resistor chain between its anode and -120 volts. In this condition, the anode is at about 100 volts, and the valve has a gain of about 20, so that the grid fall in potential gives rise to a larger increase in the anode potential. This rise is fed back to

2.3.

the grid of the value V,, which is normally non-conducting, its grid being held rather less positive than that of the value V_3 by the resistor chain. This then causes a fall in the anode potential of V, which is again fed to the grid of V_3 causing its anode potential to rise still more. The process is thus accumulative and goes on until the roles of the two values are interchanged, V, being now fully conducting and V_3 cut off.

The anode voltage of V_1 has thus dropped about 200 volts and the fall has been passed on to the counter wire which is therefore below threshold potential, and the counter is insensitive to the incoming radiations. This state of affairs holds until the negative voltage on the grid of V_3 has leaked away in a time interval controlled by the values of C and R. Then V_3 starts conducting again and the above cycle is repeated until the circuit comes back to its normal condition with V_1 non-conducting and V_3 fully conducting. The anode of V_1 has thus risen 200 volts causing the counter wire to be restored to its normal working voltage, and so is ready to receive the next pulse.

The diode V_2 ensures rapid recovery to full sensitivity at the end of the square wave. The overall sensitivity of the circuit to input pulses from the counter is due to the amplification of V_3 and is controlled by the relative bias of the two valves, which is adjusted by the potentiometer, R.

Negative pulses to the counting equipment are taken off the anode of V, through a cathode follower, which has a high input impedance and a low output impedance, and therefore protects the quenching circuit from the effect of the self-capacity of the connecting cable. In this way the



quenching circuit can be placed as near as possible to the counter while the rest of the equipment can be at a reasonable distance away from the X-ray equipment.

In practice, two such circuits, one for each counter, were wired up as one complete unit, together with a simple pulse generator. This can be switched on to supply pulses to check the action of the scaling units.

Three counting rates are available :-

| | 1. | 125 | pulses | per | second |
|--|----|------|--------|-----|---------|
| | 2. | 72.5 | pulses | per | second |
| n an | з. | 3.42 | pulses | per | second. |

The circuit diagram for the complete quenching unit is shown in fig (2.4).

29

This circuit registers and totalizes the pulses recieved from the quenching unit, and is based essentially on the well known Scale of Two circuit.

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(a) The Scale of Two Circuit.

The Scale of Two circuit used here together with suitable values for the components, is shown in fig (2.5) and is based on the well known Eccles-Jordan trigger circuit, which in this case, is symmetrically coupled to a single source of triggering by means of two diodes. The circuit has two stable states, each with one valve conducting and the other cut off, and is triggered from one state to the other by successive identical negative pulses which arrive via the double diode to whichever anode that is the more positive.

Let us suppose that the circuit is in the state where V_2 is conducting; its anode potential will be approximately 150 volts and its cathode at + 80 volts, while the grid will be held at about + 82 volts by virtue of grid current flow. Then V, will be cut off and its plate will be at about 290 volts because of the slight current drain (0.5 mA) through the resistor chain between H.T. and earth. If now, the input voltage drops suddenly from 300 volts to about 250 volts, the grid potential of V_2 immediately goes negative, and the plate potential starts to rise rapidly, and consequently the grid potential of V, rises so that V, begins to conduct and accumulative action causes the circuit

2.4.







to proceed towards its other equilibrium state. Before that state - equivalent to the original state - is reached, however, the plate of V_2 is caught by its associate diode at 250 volts. If now, the input voltage returns quickly or slowly to 300 volts, there is no effect on the trigger circuit other than that the V_2 plate returns to 290 volts, to bring the circuit to the exact mirror image of the original state.

During this process the output of the Scale of Two rises from 250 to 290 volts. On the application of a second trigger signal to the unit, however, the same cycle of operations is repeated with the difference that the roles of V, and V₂ are interchanged, so that now the output drops suddenly from 290 to 250 volts. The circuit, thus, passes on every second pulse, so that we effectively halve the number of pulses received during a counting run.

The state of the circuit at any instant is indicated by the small neon bulb, which is OFF when V_2 is conducting, and ON when V_2 is not conducting.

(b) The Scale of Ten Circuit.

Many scales of two may be connected in cascade, thus providing scaling factors which are powers of two. It is more desirable, however, to have a Scale of Ten circuit, which simplifies greatly the computation of total counts during counting operations.

The circuit built for this work is based on the principle due to Rotblat, Sayle, and Thomas" and is shown schematically in fig (2.6).



It consists of four units, three of which are standard Scales of Two, while the fourth is a modified Scale of Two arranged to work an electronic switch between the first and second units. With the eighth pulse the modified Scale of Two is turned over into its second stable position and the electronic switch opens, so that the tenth pulse instead of going into the second Scale of Two enters the fourth unit to turn it over into its original stable position so ejecting an output pulse.

The complete circuit diagram of the Scale of Ten used is shown in fig (2.7). By momentarily operating the reset switch, a potential of +80 volts is placed on the grids of the right hand triodes to make them conducting and all the neon bulbs are extinguished. The units are then in the zero state, and the circuit is ready for counting. During a counting run, each valve then goes over into its non-zero position on the arrival of the appropriately numbered pulse and the corresponding neon lights up. The lit neon lamps correspond respectively to 1, 2, 4, and 8 pulses, so that at the end of a counting run, the sum of the numbers indicated by the lamps gives the number of counts to be added to the number of output pulses (multiplied by ten) in order to obtain the total count.

(c) The Complete Counting Unit.

In the complete counting unit we have two Scales of Ten in series, so that one output pulse is obtained for every hundred input pulses. In this case, the neon bulbs associated with the second Scale of Ten correspond to 10, 20, 40, and 80 pulses respectively



since the unit receives one pulse from the first Scale of Ten for every ten pulses from the counter. A circuit diagram of the whole counting unit is shown in fig (2.8).

Negative pulses enter the unit via a cathode follower V_1 and are then applied to V_2 to be amplified and inverted. The positive pulses formed are then differentiated, and the positive pips pass to the cathode coupled flip-flop (V_4 and V_5) through the doide V_3 .

 V_4 is normally non-conducting so that the small pips trigger the circuit to give positive pulses at the anode of V_5 , of width controlled by the potentiometer. These output pulses are of constant amplitude and duration substantially independent of the form of the input pulses which vary for different counters, and because of losses in the cable connecting the counting unit to the quenching circuit. The cathode follower V_6 then supplies the output pulses. It is set about three volts beyond cut-off bias so that any spurious pulses arising from the action of the flip-flop as an amplifier for very small input pulses, are suppressed. It also serves to protect the pulse equalising circuit from being loaded by the output connection. V_7 then amplifies and inverts the pulses to form negative input pulses to operate the scaling units.

For every hundred input pulses we obtain one negative output pulse, which triggers off the multivibrator formed by V_8 and V_q . This then gives a positive pulse on to the grid of the output stage containing the P.O. message register. In order to obtain a sufficient current pulse (about 20 mA) to operate the register, the stage contains two 6AC7 valves wired in parallel.



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POWER SUPPLIES

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These are mains operated power units which supply the high tension and heater voltages, required by the counting equipment, and also the extra high tension for the counter tubes. The mains supply is first of all passed through a 500 watt constant voltage transformer to give some degree of stabilisation before it enters the units. The transformer gives out 230 volts when the input varies between 190 and 260 volts.

(a) The H.T. Power Supply.

This unit supplies 300 volts D.C. for the counting circuits, 6.3 volts A.C. for all valves having their cathodes at earth potential, and 6.3 volts A.C. for the diodes with cathodes at H.T.potential.

The 300 volt D.C. output is stabilised for both changes of input voltage and load current. In order to avoid drawing the heavy current required by the mechanical register from this stabilised output, the unit also contains a separate H.T. supply for this purpose. The complete circuit diagram is shown in fig (2.9).



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(b) The E.H.T. Power Supply.

This unit consists essentially of a transformer and half wave rectifier, followed by the usual smoothing chokes and condensers. It gives two outputs - one for each counter - which are taken off a potentiometer network, so that voltages variable between 800 and 2000 volts can be obtained as required. These are measured by an electrostatic voltmeter, V, reading from 0 - 3500 volts.

The stability of the output can be improved when necessary by the insertion of a stabilising valve, V₁. Increase of output voltage as the result of either increase of load resistance or input voltage, changes the negative grid bias on the valve so as to reduce the plate current and hence the output voltage.

The complete circuit diagram of the unit is shown in fig (2.10).





Fig 2.12 General view of the apparatus

SETTING-UP PROCEDURE

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and

GENERAL TEST OF THE COUNTING SYSTEM

The complete Geiger-Muller counting system is shown schematically in fig (2.11), with the counter tubes set to receive the collimated beams from the focussing monochromator. A photograph of the complete apparatus is shown in fig (2.12).

We shall now outline how the counting system is set up, and the counters tested, ready for X-ray intensity measurements.

(1) With both Geiger-Müller tubes disconnected and the -120 volt bias battery connected to the quenching unit, the H.T. power unit is switched on, and the sensitivity controls on both quenching circuits adjusted just below the points where the circuits begin to oscillate. The whole equipment is then allowed a few minutes to warm up, in order to ensure reasonable temperature equilibrium of the component parts.

(2) The action of both scaling units is then checked by means of the calibrated pulse oscillator. It is first of all set to the low frequency range, and a visual check on the action of the scaling circuits made by watching the lighting up sequence of the small neon indicators. Secondly, it is set on a higher frequency range, and the two P.O. message recorders kept under observation in order to check the action of counting without missing any pulses. Lastly, the number of counts observed during a set period of time is compared with the known pulse rate of the oscillator.



It is then switched off, and no counts should be recorded due to electromagnetic pick-up from the mains, etc

(3) The E.H.T. power unit is switched on, and the high voltage on both circuits adjusted to about 2 Kv. There should be no counts. If counts do occur, it is reasonable to suspect bad connections or a breakdown of the insulation of the components carrying the high voltage.

(4) We now adjust the E.H.T. voltages to a minimum, and switch off before connecting the counter tubes to their respective counting circuits. The power supply is again switched on, and allowed a few minutes to warm up, and a long-life radioactive source mounted near each counter. The voltages on both counters are then slowly increased, until they start to count.

(5) We then determine the background counting rates of both counters, and also plot their plateaux, using the long-life radioactive sources. A source is placed in front of each counter, and we take a five minute count at each of several operating voltages. The counting rate against voltage curve is then plotted for each counter as shown in fig (2.13). The curve should begin at a definite threshold voltage, then rise sharply to a certain value where it remains nearly constant over a range of voltage depending on the individual counter. Beyond this range, the curve begins to rise again, the conditions for continuous discharge being rapidly reached.

If the curves obtained are not of this form, the counters must be refilled or replaced.

(6) We then choose an operating voltage just above the knee of the counting rate against voltage curve, and adjust

the E.H.T. to this value.

(7) We now determine whether the counters can operate correctly, by checking experimental counting results to see if they are truly statistical.

A long-life radioactive source is mounted in front of each counter, and counts made over a number of consecutive one minute intervals as shown in table (2.1).

TABLE 2.1

Consecutive one minute counts with radioactive source.

| СС | UNT | ER | 1 | C | OUNT | ER | 2 |
|---------------------|--------|--------------------|---------------------|---------------------|----------------------|--------------------|--------------------------|
| Counter Readings | Counts | A _r - Ā | $(A_n - \bar{A})^2$ | Counter Readings | Counts | A ₆ - Ā | $(A_n - \overline{A})^2$ |
| 188290 | 110 | | | 474095 | 1. 1. 1. 1. 1. 1. | nie Nie | |
| 189700 | 1410 | - 40 | 1600 | 474430 | 335 | 32 | 1024 |
| 19 11 60 | 1460 | + 10 | 100 | 474820 | 390 | +23 | 529 |
| 192610 | 1450 | - 0 | 0 | 475235 | 415 | +48 | 2304 |
| 194100 | 1490 | + 40 | 1600 | 475610 | 375 | + 8 | 64 |
| 195580 | 1480 | + 30 | 900 | 475970 | 360 | - 7 | 49 |
| 197020 | 1440 | - 10 | 100 | 476335 | 365 | 2 | 4 |
| 198420 | 1400 | - 50 | 2500 | 476715 | 380 | +13 | 169 |
| 199800 | 1560 | +110 | 12100 | 477060 | 345 | -22 | 484 |
| 201200 | 1400 | - 50 | 2500 | 477438 | 378 | +11 | 121 |
| 202610 | 1410 | - 40 | 1600 | 477828 | 390 | +23 | 529 |
| 204080 | 1470 | + 20 | 400 | 478190 | 352 | -15 | 225 |
| 205500 | 1420 | - 30 | 900 | 478560 | 370 | + 3 | 9 |
| 206970 | 1470 | + 20 | 400 | 478906 | 346 | -21 | 441 |
| 208400 | 1430 | - 20 | 400 | 479265 | 359 | - 8 | 64 |
| 209860 | 1460 | + 10 | 100 | 479610 | 345 | -22 | 484 |

The arithmetic mean \overline{A} of a series of counts (A, A₂....A_n) for each counter is calculated, and the deviations (A_n - \overline{A}) of the individual values from the mean, computed. It is noted that the positive and negative values of these residuals occur with about equal frequency. The table also gives the squares of the residuals (A_n - \overline{A})², and it may be shown that the standard deviation Δ for \overline{A} is given by

$$\Delta = \left[\sum_{n} (A_n - \overline{A})^2 / n(n - 1) \right]$$

where n is the number of observations made.

Again, if we assume the statistical fluctuations to follow Poisson's Law, the standard deviation of the total number of counts is given by

$$\triangle = \left[\sum_{n} \mathbb{A}_{n}\right]^{\frac{1}{2}} = \mathbb{N}^{\frac{1}{2}}$$

so that, in this case, the standard deviation of A would be

$$\triangle' = \frac{1}{n} N^{\frac{1}{2}}$$

When the standard deviation is calculated by the two different methods we have

Counter 1.

 $\Delta = 10.95$ $\Delta' = 9.83$

Counter 2.

 \triangle = 5.57 \triangle = 4.95

and the reasonable agreement obtained is good proof that the events were random. This would not be so if the counters had manufactured spurious counts,

Lastly, from the readings we see that there is no gradual change in the two counting rates with time, unless it is smaller than the statistical variation of the individual readings. Such a change would also show up as a definite grouping of the positive and negative residuals at opposite ends of the table.

(8) All that remains, is to test the response of the counters to the actual X-ray beams.

The X-ray tube is switched on, and the pressure adjusted until it is working reasonably steady. The lead shields that cover the monochromatic slits are then removed, and the counters aligned in the beams for maximum response. The beams are also collimated as described in Part 1, Section 4, of this thesis.

We check that no counts occur with the E.H.T off. If counts are obtained, the counting equipment is not effectively screened from the X-ray installation, and is picking up electromagnetic disturbances from the electrical system.

(9) Again, a check is made on the statistical nature of the counting data.

Readings are taken for ten consecutive one minute counting periods with both counters simultaneously. A typical set of such readings is shown in table (2.2), where the residuals and their squares are also tabulated. The output of the X-ray tube is kept as steady as possible during this counting operation.

As before the standard deviation is calculated from the readings by the same methods. The values obtained are

TABLE 2.2

Consecutive one minute counts with X-rays.

| COUNTER 1 | | | | COUNTER 2 | | | |
|---------------------|--------|--|---------------------|---------------------|----------|-------------------|--------------------------|
| Counter Readings | Counts | A _n -Ā | $(A_n - \bar{A})^2$ | Counter Readings | Counts | A _n -Ā | $(A_n - \overline{A})^2$ |
| 309800 | | $\left\{ \left\{ f_{i}^{(1)}, f_{i}^{(2)}, f_{i}^{(2)$ | | 538300 | Str. Chi | he and | |
| 310380 | 580 | - 8 | 64 | 539400 | 1140 | - 2 | 4 |
| 310970 | 590 | + 2 | 4 | 540520 | 1080 | -62 | 3844 |
| 311580 | 610 | +22 | 484 | 541685 | 1165 | +23 | 529 |
| 312160 | 580 | - 8 | 64 | 542800 | 1115 | -27 | 729 |
| 312760 | 600 | +12 | 144 | 544010 | 1210 | +68 | 4624 |
| 313370 | 610 | +22 | 484 | 545190 | 1180 | +38 | 1444 |
| 313960 | 590 | + 2 | 4 | 546290 | 1100 | -42 | 1764 |
| 314530 | 570 | -18 | 324 | 547370 | 1080 | -62 | 3844 |
| 315100 | 570 | -18 | 324 | 548570 | 1200 | +58 | 3364 |
| 315680 | 580 | - 8 | 64 | 549720 | 1150 | + 8 | 64 |

Counter 1

 $\Delta = 4.67$ $\Delta' = 7.67$

and the second second

△ = 10.69

In this case, the agreement between the standard deviations is not so good, because the tube output is not constant, thereby causing variations in the individual readings, which are not statistical.

The ratio of the two beams, however, should not depend on tube fluctuations, and so the ratio of the two counts should only show a statistical variation.

| RUN | Counter 1 Counts | Counter 2 Counts | Ratio R_n | $R_n - \overline{R}$ | $\left(\mathbb{R}_{n}-\overline{\mathbb{R}}\right)^{2}$ x 10 ⁶ |
|-----|---------------------|---------------------|-------------|----------------------|---|
| 1 | 580 | 1140 | 0.5088 | 0.0067 | 44.9 |
| 2 | 590 | 1080 | 0.5464 | +0.0309 | 955.0 |
| 3 | 610 | 1165 | 0.5235 | +0.0080 | 64.0 |
| 4 | 580 | 1115 | 0,5202 | +0.0047 | 22.1 |
| 5 | 600 | 1210 | 0.4960 | -0.0195 | 380.2 |
| 6 | 610 | 1180 | 0.5169 | +0.0014 | 1.9 |
| 7 | 590 | 1100 | 0.5364 | +0.01.09 | 118.8 |
| 8 | 570 | 1080 | 0,5278 | +0.0123 | 151.3 |
| 9 | 570 | 1200 | 0,4750 | -0.0405 | 1641.0 |
| 10 | 580 | 1150 | 0.5043 | -0.0112 | 125,4 |

Ratio of the Counts obtained with X-rays

TABLE 2.3

In table (2.3) the ratio, R_n of the two beams is computed for each of the ten consecutive one minute readings, and the residuals and their squares calculated. From these, the standard deviation obtained for the mean value of the ratio is

△ = 0.0063

If we assume the variations to follow Poisson's Law the standard deviation obtained for the ratio of the total counts recorded during the measurement is

△ = 0.0073

which agrees quite well with the measured value. The variations are thus entirely statistical, and the ratio is substantially independent of the tube fluctuations as expected.

The apparatus is now ready for intensity measurements on thin foils.

PART 3.

THE ABSORPTION OF X-RAYS BY THIN METAL FOILS.

INTRODUCTION.

3.1

When a beam of X-rays passes through a thin sheet of material, some of the X-ray photons are absorbed and some scattered by the atoms of the material. In order to compare the amount absorbed by different specimens, the fractional decrease in the intensity of the beam as it traverses unit distance through the substance is used as a measure of the process, and is called the <u>linear absorption</u> <u>coefficient</u>. In the case of a <u>pure monochromatic beam</u> of X-rays, this coefficient is a constant for a particular material and is independent of the distance travelled by the beam.

Mathematically, if dI is the decrease in the intensity, I, of a narrow parallel beam as it travels a distance dx through the material, we may write

 $-\frac{dI}{Idx} = \mu = (constant independent of x)$

which on integration gives

 $\log_e I = -\mu x + constant$

Now, if we denote the intensity of the X-ray beam when x = 0, by I, we have

 $constant = \log_e I_o$

so that

loge I = loge I,- µx

I - I e^{-µx} -----(3.1)

This equation then, gives the intensity, I, of a narrow parallel monochromatic beam after it has passed normally through a thin foil of thickness x. If the thickness of the foil is expressed as the mass per unit area ω (= ρ x) where ρ is the density of the material the equation becomes

$$I = I_{e} e^{-\frac{\mu}{\rho}\omega}$$
 (3.2)

where the constant is now (μ / ρ) and is called the total mass absorption coefficient.

Expressed in this way, the absorption coefficient is independent of the physical state of the absorbing medium and is therefore a more convenient measure of the absorption process than μ itself. From equation (3.2) we have

$$(\mu_{\rho}) = \frac{1}{\omega} \log_{e} \frac{I_{o}}{I} \qquad (3.3)$$

and note that it is only strictly true if certain conditions are fulfilled by the X-ray beam and absorbing foil respectively. These are :-

(a) For the X-ray beam.

- (1) It must be truly monochromatic.
- (2) It must be parallel, otherwise different rays will traverse different thicknesses of material.
- (3) It must be narrow, or the transmitted beam will also contain a small amount of fluorescent and scattered X-rays to add to its power.

(b) For the absorbing foil.

(1) It must be of high purity.

(2) It must be homogeneous, otherwise different parts will absorb differently. (3) It must be of uniform thickness or different rays will traverse different thicknesses of material.

Under such conditions, the equation (3.3) will give good values of the absorption coefficients if ω and $\log_{e}\left(\frac{I_{o}}{T}\right)$ are measured accurately.

During the present investigation all possible precautions were taken to ensure that these conditions were satisfied.

- (a) Two divergent beams of monochromatic X-rays were produced by the fine powder focussing monochromator.
- (b) They were collimated into narrow beams by the slit systems.
- (c) The beam intensities were accurately compared by the Geiger counter, and any variations due to tube fluctuations were eliminated.
- (d) The foils used, were very carefully prepared from high purity metals, and their thicknesses accurately determined.
3.2. PREPARATION OF FOILS.

(a) Rolling of foils.

Most of the high purity metals used in this work were available in rod, sheet, or lump form as supplied by Messrs Johnson and Mathey, and were reduced to thin foils by rolling in a small hand-operated rolling mill fitted with hardened steel rollers.

First of all, the rollers were carefully wiped clean and then washed with distilled water and alcohol before use. A small piece of pure metal was then passed between the rollers several times, gradually reducing its thickness each time. In the early stages of the reduction, the rolling process was quite simple - foils 0.05 cms thick being very easily produced. With further reduction, however, the tendency to crack became great, even with the rolling carried out with the utmost care.

To overcome this difficulty, several sheets were rolled together to keep the overall thickness relatively high, and several usable foils down to a thickness of 0.0005 cms were obtained this way. On further reduction they became porous and of a net-like appearance, and quite unsuitable for absorption measurements.

Since cold-work harden the metals, the foils were subjected to heat treatment at various intermediate stages in the rolling process in order to re-soften them for further rolling.

Satisfactory foils of Aluminium, Iron, Nickel, Copper, Zinc, Molybdemum and Palladium were obtained and all of them subjected to a thorough inspection for pin-holes and any other irregularities which would affect the absorption measurements. In the case of Beryllium, which is too hard and brittle to produce foils by rolling, another method was used. Flatish lumps of this metal were taken and two sides ground down quite flat and parallel to each other, to give slabs of the required thicknesses. Since the absorption coefficients of Beryllium at the wavelengths used here, are quite small, relatively thick specimens (<0.5 cms) could be used.

Specimens of Carbon were also prepared by a similar method. In this case, suitable flat graphite sheets were filed down to the appropriate thicknesses.

(b) Measurement of foil thickness.

The relatively thick foils (Beryllium and Carbon) were measured directly by means of a micrometer, the mean of a large number of readings being taken as the correct values. In the case of very thin foils known areas of them were carefully weighed and the thickness determined knowing the density of the metal.

(c) Mounting of foils.

Each foil was mounted on a stiff cardboard frame , having a rectangular hole cut in the centre. The foil was laid flat on the frame, covering the hole, and its edges held in position by strips of adhesive cellophane. These frames were fitted in the brass holder sliding along the steel guide-way, and could be clamped in any required position in the monochromatic beam. METHOD OF MEASURING 1/1, AND CORRECTION FACTORS.

(a) Ideal counters.

Let us suppose that in the first instance the beams are detected by ideal Geiger counters, that is, by counters that have no background count and no dead-time, and that counts are made over three consecutive and equal intervals of time T, for both beams simultaneously under the conditions shown in the following table.

| FTA TOT TO | - C: R | |
|------------|--------|--|
| 1882112 | O o de | |
| | | |

| 2.8 | : 194 S. A | Beam 1 | Beam 2 |
|-----------|------------|-----------------------------------|-----------------|
| | Run 1 | Unhindered beam | Unhindered beam |
| | Run 2 | With foil inter- posed in beam | Unhindered beam |
| ist de la | Run 3 | With foil removed | Unhindered beam |

Let the counts recorded during these three runs be $n_1 n_2$ and n_3 for the first beam, and $n_1^* n_2^* n_3^*$ for the second beam, while the sensitivities of the counters are $k_1 k_2 k_3$ for Counter 1, and $k_1^* k_2^* k_3^*$ for Counter 2, assuming them to change slightly during the measurement. The energies entering the counters during these three runs are therefore

| Run | 1 | E, = | k, n, | 9 | E, | - | k'n' |
|-----|---|------------------|-------------------------------|---|-----------------------------|---|------------------------------|
| Run | 2 | E ₂ = | k ₂ n ₂ | 9 | E 2 | = | $k_2^{\dagger}n_2^{\dagger}$ |
| Run | 3 | E ₃ = | k ₃ n ₃ | 9 | E ^s ₃ | = | k'n'3 |

Now, since the tube fluctuations affect each beam in the same proportion, the ratio of their energies will be independent of the changes. These normalized energies are

3.3

$$E_{o} = \frac{E}{E_{i}} = \frac{k_{i}n_{i}}{k_{i}n_{i}} - (a)$$

$$E = \frac{E}{2}E_{2} = \frac{k_{i}n_{i}}{2^{2}}E_{2} - (b)$$

$$E_{o} = \frac{E}{3}E_{3} = \frac{k_{i}n_{i}}{3^{3}}E_{3} - (c)$$

From (a) and (c)

$$E_{o} = \frac{k_{i}n_{i}}{k_{i}^{i}n_{i}^{i}} = \frac{k_{i}n_{j}}{k_{3}^{i}n_{3}^{i}} = \frac{k_{i}n_{i} + k_{3}n_{3}}{k_{i}^{i}n_{i}^{i} + k_{3}^{i}n_{3}^{i}}$$

Dividing by (b) and we obtain

$$\frac{E}{E} = \left(\frac{k!n!}{2}\right)^{2} \left(\frac{k!n! + k!n!}{k!n! + k!n!}\right)$$
$$= \left(\frac{n!}{2}\right)^{2} \left\{\frac{(k!k!)n! + k!n!}{(k!k!)n! + k!n!}\right\}^{2} ---(3.5)$$

Let us assume that any change in the sensitivity of a counter will be in the form of a slight drift with time due, for example, to changes in the composition of the gas or a very small leak. We can then say, for the first counter

$$k_{1} = k_{2} + \delta \quad \text{and} \quad k_{3} = k_{2} - \delta$$
so that $\frac{k_{1}}{k_{2}} = 1 + \frac{\delta}{k_{2}} \quad \text{and} \quad \frac{k_{3}}{k_{2}} - 1 - \frac{\delta}{k_{2}}$

Similarly for the second counter

$$\frac{k_{1}^{*}}{k_{2}^{*}} = 1 + \frac{\delta'}{k_{2}^{*}}$$
 and $\frac{k_{3}^{*}}{k_{2}^{*}} = 1 - \frac{\delta'}{k_{2}^{*}}$

Substituting these in equation (3.5) we obtain

$$\frac{E}{E} = \left(\frac{n_2^*}{n_2}\right) \left\{ \frac{(n_1 + n_3) + \delta'_{k_2}(n_1 - n_3)}{(n_1^* + n_3^*) + \delta'_{k_2}(n^* - n^*)} \right\}$$
(3.6)

Now $(n_1 - n_3) < < (n_1 + n_3)$ and δ/k_2 is small, and we can therefore neglect $(\delta/k_2)(n_1 - n_3)$ in comparison with $(n_1 + n_3)$. Similarly, we can neglect $(\delta'/k_2)(n_1 - n_3)$ so that equation (3.6) can be written

$$\frac{E_o}{E} = \left(\frac{n!}{2}\right) \left(\frac{n+n}{n!+n!}\right)$$
(3.7)

The method gives good values of $\frac{E}{E}$, substantially independent of tube variations, and also of slight changes in the sensitivities of the counters.

If the cross-sectional areas of the two beams are A and A' respectively, it follows that the intensities of the beams entering the counters during these three measurements are

| 1.1.1 | tea est | | Be | am 1 | 97 JULE | Be | am 2 |
|-------|---------|----------------|---------|--------------------|---------|---------|--------|
| Run | 1 | I, | <u></u> | E, /AT | I¦ | - | E'/A'T |
| Run | 2 | I | - | E2/AT | I'2 | * | E'/A'T |
| Run | 3 | I ₃ | | E ₃ /AT | I'3 | <u></u> | E'/A'T |

so that the normalised intensities which are independent of tube fluctuations are

$$I_{o} = \frac{I}{I_{I_{i}}} = \left(\frac{E}{I_{E_{i}}}\right) \left(\frac{A^{*}}{A}\right) = E_{o}\left(\frac{A^{*}}{A}\right)$$
$$I = \frac{I}{2}{I_{2}} = \left(\frac{E}{2}{E_{2}}\right) \left(\frac{A^{*}}{A}\right) = E\left(\frac{A^{*}}{A}\right)$$
$$I_{o} = \frac{I}{3}{I_{3}} = \left(\frac{E}{3}{E_{3}}\right) \left(\frac{A^{*}}{A}\right) = E_{o}\left(\frac{A^{*}}{A}\right)$$

giving

$$I_o/I = E_o/E$$

and equation (3.7) then becomes

$$\mathbf{I}_{o}/\mathbf{I} = \frac{\begin{pmatrix} \mathbf{n}_{i} + \mathbf{n}_{3} \\ \hline \mathbf{2} \end{pmatrix} \begin{pmatrix} \mathbf{1} \\ \mathbf{n}_{2} \end{pmatrix}}{\begin{pmatrix} \mathbf{n}_{i}^{\dagger} + \mathbf{n}_{3}^{\dagger} \\ \hline \mathbf{2} \end{pmatrix} \begin{pmatrix} \mathbf{1} \\ \mathbf{n}_{2}^{\dagger} \end{pmatrix}}$$
$$= \frac{\begin{pmatrix} \mathbf{N}_{o}/\mathbf{N} \end{pmatrix}}{\begin{pmatrix} \mathbf{N}_{o}^{\dagger}/\mathbf{N} \end{pmatrix}} - \dots (3.8)$$

where $N_{o} = \frac{n_{1} + n_{3}}{2}$; $N = n_{2}$; $N_{o}^{*} = \frac{n_{1}^{*} + n_{3}^{*}}{2}$; and $N_{1}^{*} = n_{2}^{*}$

(b) Correction for Background Count.

In practice, a counter will always have its own characteristic background count, due to the stray radiation in the laboratory, and this will always be included in any particular measurement.

It must therefore be determined, and subtracted from a recorded count in order to obtain the true recorded count corresponding to the intensity being measured.

In this particular case, instead of making three consecutive runs of duration T each, we now make five runs - the first and last runs to measure the background radiation only. During these two runs the actual monochromatic beams are cut off from the counters by means of lead shields placed over the monochromator slits.

The complete counting technique with a particular foil ω is now as shown in table (3.2), and the counts corrected for background as given in table (3.3)

COUNTING TECHNIQUE

TABLE 3.2

| N TEN | Beam 1 | , A | Beam 2 | |
|-------|-----------------------|----------------|-----------------|-----------------------------|
| Run | Measurement | Count | Measurement | Count |
| 1 | Background | n | Background | nt |
| 2 | Unhindered beam | n ₂ | Unhindered beam | n' |
| 3 | With foil in position | n ₃ | Unhindered beam | n'3 |
| 4 | With foil removed | n ₄ | Unhindered beam | n ¹ ₄ |
| 5 | Background | n ₅ | Background | n'5 |

COUNTS CORRECTED FOR BACKGROUND

TABLE 3.3

| | Beam 1 | Beam 2 |
|------------------|---------------------------|---|
| Initial beam | $N_{1} = (n_{2} - n_{1})$ | $\mathbf{N}_{1}^{*}=\left(\mathbf{n}_{2}^{*}-\mathbf{n}_{1}^{*}\right)$ |
| Transmitted beam | $N_2 = n_3 - (n_1 + n_5)$ | $N_2' = n_3' - (\frac{n_1' + n_5'}{2})$ |
| Final beam | $N_3 = (n_4 - n_5)$ | $N_{3}^{i} = (n_{4}^{i} - n_{5}^{i})$ |

The intensity ratio $\binom{I}{I}$ is still given by equation (3.8) where this time

 $N_{0} = \frac{N_{1} + N_{3}}{2}; N = N_{2}; N_{0}^{*} = \frac{N_{1}^{*} + N_{3}^{*}}{2}; \text{ and } N^{*} = N_{2}^{*}$

A practical example of this counting technique is shown in table (3.4). The readings are taken from the absorption measurements on Iron with Co Ka, radiation.

TABLE 3.4

EXAMPLE OF COUNTING TECHNIQUE.

| | | | Counter 1. | | | | | Counter 2 | | | |
|------|---------------------|--------|------------------------|---------------|--|---------------------|----------|------------------------|---------|---------------|--------|
| | Counter Readings | Counts | Counts — Background | No | N | Counter Readings | Counts | Counts — Background | N°0 | N | ¥/1 |
| 10 | 287135 | | | | | 227825 | | | | | |
| Ø | 287100 | 35 | 8. V - 27 M | | - | 227700 | 125 | b sold a set of the | 1 | | |
| T | 289605 | | | | | 230668 | | | 1 | 1 . J | |
| ** c | 287100 | 2505 | 2470 | | | 227900 | 2768 | 2643 | | | |
| I | 291018 | | | | | 233269 | | | | 1.1.1.1.1.1.1 | |
| | 289600 | 1418 | 1385 | 2392 | 1385 | 230700 | 2569 | 2422 | 2534 | 2422 | 1.645 |
| I | 293344 | 0244 | 0234 | | | 235895 | | | | | |
| ° | 591000 | とう後後 | 2914 | 1.1 | 1.0 | 233300 | 2595 | 2426 | | | |
| B | 290000 | 20 | S. 1814 | | ÷. | 235069 | 300 | | | | 1 |
| | 205504 | 90 | Kara and an | | | 239900 | 108 | Carlor Marca Carlo | | | |
| I | 203300 | 2201 | 2264 | | | 030766 | 0600 | 0453 | - | | 1.1 |
| | 297030 | 22 J t | 160 Galler 725 | | | 241417 | 6.96563 | 6 C C C | | | n |
| I | 295600 | 1430 | 1395 | 2342 | 1395 | 238800 | 2617 | 9409 | 0626 | 0400 | 3 000 |
| - | 299460 | | | ora dia manda | 11 11 11 11 11 11 11 11 11 11 11 11 11 | 244198 | 60% ds f | 672 6765 | 6000 | 6496 | 1.0000 |
| I. | 297000 | 2460 | 2420 | | | 241500 | 2698 | 2617 | | 1.1 | |
| 17.0 | 299440 | | Contraction of the | 1 C C | | 244281 | | 10 10 45 T | · · · · | | |
| D | 299400 | 40 | 267.1 | | | 244200 | 81 | | · | | |
| T | 302038 | | | | | 247008 | N 1 0 | | | | |
| *0 | 299400 | 2638 | 2598 | | | 244300 | 2708 | 2627 | | | |
| T | 303531 | | | | | 249804 | | | | | |
| 4 | 302000 | 1531 | 1493 | 2603 | 1493 | 247100 | 2704 | 2614 | 2604 | 2614 | 1.750 |
| τ | 306145 | | | | | 252581 | | | | | |
| 50 | 303500 | 2645 | 2608 | | 1 A 1 | 249900 | 2681 | 2581 | | | |
| B | 306137 | | | 1. C | - Y | 252700 | | | | | |
| | 306100 | 37 | | | | 252600 | 100 | | | | |

57

(c) Correction for Counting losses.

Lastly, a practical counter will miss a certain number of counts due to its inherent dead-time, so that a recorded count in time T must be corrected in order to ascertain the true count.

This correction is a fairly simple matter in the case of a continuous source of radiation, but is more complicated with a source of varying intensity, such as is encountered here. In this case, the output of the selfrectifying X-ray tube is not continuous, but occurs in bursts or pulses of about 1/150th sec duration, separated by comparatively long intervals during which time the tube gives no output. This is because the X-rays are only produced during a portion of one half the voltage cycle when the voltage is in excess of the critical excitation potential for the characteristic radiation being generated.

Let us suppose that the actual rate of counting at any instant of time t is n_t while the recorded rate is n_t per second. Hence in a small interval of time δt , we have

> Actual number of counts = $n_t \delta t$ Observed number of counts = $n_t^{\dagger} \delta t$

so that the number of counts missed is $(n_t \delta t - n_t' \delta t)$. If the dead-time \mathcal{T} occurs only after recorded counts, the counter is insensitive for a portion $(n_t' \delta t)\mathcal{T}$ of the total counting time δt , and we have therefore missed $(n_t)(n_t' \delta t)$ counts.

Equating these two values of the lost counts we obtain

$$n_t \delta t - n_t \delta t = n_t n_t \delta t(T)$$

to relate the observed and actual counting rates.

53

When we count for a long period of time T we obtain on integration

$$\int_{0}^{T} n_{t} \delta t - \int_{0}^{T} n_{t}' \delta t = \int_{0}^{T} \mathcal{T}(n_{t} n_{t}' \delta t)$$

$$N - N' = \int_{0}^{T} \mathcal{T}(n_{t} n_{t}' \delta t)^{----(3.9)}$$

where $N = \int_{0}^{T} n_{t} \delta t =$ actual number of counts in T secs

and $N' = \int_{0}^{T} n'_{t} \delta t = observed number of counts in T secs$

(12) According to W.Cochran, we can approximate for small corrections, and write

$$\frac{n_t'}{n_t} = \frac{N'}{N}$$

and the equation (3.9) then becomes

$$N - N' = \int_{0}^{T} n_{t}^{2} \left(\frac{N}{N}\right) \tau \delta t$$

$$= N N' \tau \int_{0}^{T} n_{t}^{2} \delta t / N^{2}$$

$$= N N' \tau \left[\int_{0}^{T} n_{t}^{2} \delta t / \left\{ \int_{0}^{T} n_{t} \delta t \right\}^{2} \right]$$

$$= N N' \frac{\tau' K}{T} - \dots (3.10)$$

from which, for small corrections, we have

$$N = N'/(1 - N' \frac{K\tau}{T})$$
 ----- (3.11)

It is stated ⁽²⁾that this equation holds good for corrections up to 30% of the actual count.

For a continuous source of radiation the corrected count in time T is given by

$$N = N'/(1 - \frac{N'T}{T})$$
 ----- (3.12)



By comparing the two equations, we see that the pulsating nature of the X-ray beam effectively increases the deadtime of the counter by the factor K which is given by

$$K = T \int_{0}^{T} n_{t}^{2} \delta t / \left\{ \int_{0}^{T} n_{t} \delta t \right\} \quad ----- \quad (3.13)$$

and which can be calculated from a knowledge of the voltage applied to the X-ray tube and the critical excitation potential V, of the target material.

In the present investigation the voltage waveform was considered to be of the form $V_t = V_m \cos(2\pi pt)$ and K calculated for a number of values of (V_{V_m}) . The results are shown graphically in fig (3.1) and it is seen that if the applied voltage V_m is not very much greater than the critical potential V_o the factor K is large and rapidly increases as V_m approaches V_o . Under these conditions, the counting losses would be high, and with K varying rapidly with small changes in the applied voltage, it would be extremely difficult to make adequate corrections for them.

If, on the other hand, the X-ray tube is operated so that $\frac{V_o}{V_m} < 0.5$, K is small and varies so slowly that it can be taken as a constant for small changes in the applied voltage during the counting period. It is therefore advisable to work the tube at a voltage > 2V_o in order to minimise the counting losses and make accurate corrections for them by applying equation (3.11) which can be written

$$\mathbb{N} = \mathbb{N}^{\dagger} \left(\mathbf{1} + \frac{KT}{m} \mathbb{N}^{\dagger} \right)$$

since $\frac{K\tau}{T}$ N' is small and second order terms are ignored.

It follows that every observed N in equation (3.8) must be replaced by a term of the form $N(1 + \frac{K \tau}{T}N)$ in order to correct our intensity ratio for the counts lost during

55

the measurement.

Consider the term $N_{o} = \frac{N_{1} + N_{3}}{2}$

 $N_1 + N_2$ becomes when corrected

$$N_{i} \left(1 + \frac{K \tau'}{T} N_{i}\right) + N_{3} \left(1 + \frac{K \tau'}{T} N_{3}\right)$$

$$= (N_{i} + N_{3}) + \frac{K \tau'}{T} (N_{i}^{2} + N_{3}^{2})$$

$$= (N_{i} + N_{3}) + \frac{1}{2} \frac{K \tau'}{T} \left\{ (N_{i} + N_{3})^{2} + (N_{i} - N_{3})^{2} \right\}$$

Now, $(N_1 + N_3)^2 > > (N_1 - N_3)^2$ so we may neglect the second part of the correcting term and write

$$(N_{1} + N_{3}) + \frac{1}{2} \frac{K \tau'}{T} (N_{1} + N_{3})^{2}$$

$$= (N_{1} + N_{3}) \left\{ 1 + (\frac{K \tau}{T}) (\frac{N_{1} + N_{3}}{2}) \right\}$$
that $N_{\circ} \rightarrow N_{\circ} (1 + \frac{K \tau}{T} N_{\circ})$

so t

Similarly, $N'_{o} \rightarrow N'_{o}(1 + \frac{K \tau'}{T}N'_{o})$ where τ' is now the deadtime of the second counter. become The observed counts N and N'

$$N(1 + \frac{KT}{T}N)$$
 and $N'(1 + \frac{KT'}{T}N')$

and the substitution of these terms in equation (3.8) gives

$$\frac{\mathbf{I}_{o}}{\mathbf{I}} = \left(\frac{\mathbf{N}_{o}\mathbf{N}^{\dagger}}{\mathbf{N}_{o}\mathbf{N}^{\dagger}}\right) \left\{ \frac{\left(\mathbf{1} + \frac{\mathbf{K}\tau}{\mathbf{T}}\mathbf{N}_{o}\right)\left(\mathbf{1} + \frac{\mathbf{K}\tau}{\mathbf{T}}\mathbf{N}^{\dagger}\right)}{\left(\mathbf{1} + \frac{\mathbf{K}\tau}{\mathbf{T}}\mathbf{N}\right)\left(\mathbf{1} + \frac{\mathbf{K}\tau}{\mathbf{T}}\mathbf{N}^{\dagger}\right)}\right\}$$
$$= \left(\frac{\mathbf{N}_{o}\mathbf{N}^{\dagger}}{\mathbf{N}_{o}\mathbf{N}^{\dagger}}\right) \left\{\mathbf{1} + \frac{\mathbf{K}\tau}{\mathbf{T}}\left(\mathbf{N}_{o}-\mathbf{N}\right) - \frac{\mathbf{K}\tau}{\mathbf{T}}\left(\mathbf{N}_{o}^{\dagger}-\mathbf{N}^{\dagger}\right)\right\} - \dots (3.14)$$

if the corrections are small and we ignore squared terms. Now, \mathcal{T}' was made equal to \mathcal{T} by a suitable choice of R and C values (fig. 2.3) in the quenching circuits, and

we can write

$$\frac{\mathbf{I}_{\circ}}{\mathbf{I}} = \left[\frac{\mathbf{N}_{\circ}\mathbf{N}'}{\mathbf{N}\mathbf{N}_{\circ}'}\right] \left[\mathbf{1} + \frac{\mathbf{K}\tau}{\mathbf{T}}\left\{(\mathbf{N}_{\circ}-\mathbf{N}) - (\mathbf{N}_{\circ}'-\mathbf{N}')\right\}\right] - \dots (3.15)$$

Hence $\binom{I}{N}_{I}$ is determined if the N's are measured experimentally in the manner described and the correction factor $\binom{K}{T}$ is known for the radiation concerned.

 $(\frac{\mu}{\rho})$ is then obtained by means of equation (3.3) which becomes, when we substitute for $(\frac{I}{\rho}/I)$ from equation (3.15)

$$\frac{\mu}{\rho} = \frac{1}{\omega} \left\{ \log_{e} \left(\frac{N_{o} N'}{N N_{o}} \right) + \log_{e} \left[1 + \frac{K \tau}{T} \left\{ (N_{o} - N) - (N_{o}' - N') \right\} \right\}$$

For small corrections $\left[\frac{K \uparrow}{T} \left\{ (N_{o} - N) - (N_{o}^{*} - N^{*}) \right\} \right]^{2} < 1$, and

we can write

$$\frac{\mu}{\rho} = \frac{1}{\omega} \left[\log_{e} \left(\frac{N_{o} N'}{N_{o}} \right) + \frac{K \tau}{T} \left\{ (N_{o} - N) - (N_{o}' - N') \right\} \right]$$

Let
$$\left(\frac{N_{\circ}N'}{N_{\circ}N'}\right) = R$$
 and $\left\{\left(N_{\circ}-N\right) - \left(N_{\circ}'-N'\right)\right\} = M$

so that

$$\frac{\mu}{\rho} = \frac{1}{\omega} \left\{ \log_{\Theta} R + \frac{K\tau}{T} M \right\}$$
(3.16)

Throughout this work, logarithms to the base 10 have been used to calculate the results, and so the practical form of the equation is

$$\frac{\mu}{\rho} = \frac{2.3026}{\omega} \left\{ \log_{10} R + C(M) \right\}$$

where $C = \frac{K\tau}{2.3026 T}$

A typical example of the application of this correction factor to the logarithm of the intensity ratio is shown The readings are from the absorption measurements carried out with Carbon absorbers and Co K α_1 radiation for which C = 20×10^{-6} .

TABLE 3.5

Example of Correction for lost counts

| N ₀ 2436 | N 413 | N: | N s | M | logR | C(M) | log. R |
|------------------------|--|--|---|---|---|---|---|
| 2436 | 413 | (and the second second | | · · · · · · · | 10 | | + C(M) |
| - A. | | 3456 | 3378 | 1945 | 0.7607 | 0.0398 | 0.8005 |
| 2413 | 391 | 3314 | 3409 | 2117 | 0.8026 | 0.0433 | 0.8459 |
| 2463 | 388 | 3430 | 3504 | 2145 | 0.8119 | 0.0439 | 0,8558 |
| 2345 | 1205 | 3139 | 3274 | 1275 | 0.3075 | 0.0261 | 0.3336 |
| 2294 | 1187 | 3180 | 3200 | 1127 | 0.2786 | 0.0231 | 0.3017 |
| 2306 | 1136 | 3225 | 3148 | 1093 | 0.2968 | 0.0224 | 0.3192 |
| 2564 | 1446 | 3430 | 3320 | 1008 | 0.2656 | 0.0206 | 0.2862 |
| 2497 | 1439 | 3221 | 3255 | 1092 | 0.2439 | 0.0224 | 0.2663 |
| 2408 | 1411 | 3360 | 3420 | 1057 | 0.2398 | 0.0216 | 0.2614 |
| | 2463 2345 2294 2306 2564 2497 2408 | 2463 388 2345 1205 2294 1187 2306 1136 2564 1446 2497 1439 2408 1411 | 24633883430234512053139229411873180230611363225256414463430249714393221240814113360 | 246338834303504234512053139327422941187318032002306113632253148256414463430332024971439322132552408141133603420 | 2463388343035042145234512053139327412752294118731803200112723061136322531481093256414463430332010082497143932213255109224081411336034201057 | 24633883430350421450.8119234512053139327412750.3075229411873180320011270.2786230611363225314810930.2968256414463430332010080.2656249714393221325510920.2439240814113360342010570.2398 | 24633883430350421450.81190.0439234512053139327412750.30750.0261229411873180320011270.27860.0231230611363225314810930.29680.0224256414463430332010080.26560.0206249714393221325510920.23980.0216240814113360342010570.23980.0216 |



÷

(d) Measurement of $\left(\frac{K\tau}{T}\right)$.

If $\log_{e} R$ is experimentally determined for a number of foils, and the values so obtained plotted against ω , the curve in the case of a monochromatic beam will be given by

$$\frac{\mu}{\rho} = \log_{e} R + \frac{KT}{T} (N - N)$$
 (3.17)

Here, the term $\frac{K \tau}{T} (N' - N')$ has been omitted because, for the mean of a number of determinations the tube fluctuations will tend to cancel out so that (N' - N') is zero.

The type of curve obtained is shown in fig (3.2) and it is seen that a tangent drawn at any point will give a negative intercept on the $\log_e R$ axis. The slope of the tangent at any point is

$$\frac{d \log_{e} R}{d \omega} = \frac{\mu}{\rho} - \frac{K\tau}{T} \frac{d(-N)}{d \omega}$$

We can write to a good degree of approximation

$$N = N_{e} e^{-\frac{(\mu)}{\rho}\omega}$$
. Hence $\frac{d(-N)}{d\omega} = \frac{\mu}{\rho}N$

and the slope of the tangent becomes

 $\frac{d \log_{e} R}{d \omega} = \left(\frac{\mu}{\rho}\right) \left(1 - \frac{K \tau}{T} N\right) \dots (3.18)$

For reasonably large values of ω , N is small and therefore, since $\frac{KT}{T}$ is also small, we can write

$$\frac{1 \log_e R}{d \omega} = (\frac{\mu}{\rho})$$

The curve therefore becomes linear for large values of ω and

the slope will give us $(\frac{\mu}{\rho})$. The equation of the tangent to the curve at any point is given by

$$\log_{e} R = \left(\frac{\mu}{\rho}\right) \left(1 - \frac{K\tau}{m}N\right)\omega + c \qquad (3.19)$$

where c is the intercept the tangent makes with the log R axis.

Substituting for log_e R from equation (3.17) and we obtain

$$\mathbf{c} = -\frac{\mathbf{K} \, \mathbf{\tau}}{\mathbf{T}} \left[N_{\mathbf{r}} - N(\mathbf{1} + (\frac{\mu}{\rho})\omega) \right] \qquad (3.20)$$

where N has a value corresponding to the point at which the tangent is drawn, and $(\frac{\mu}{\sqrt{2}})$ is given by the slope of the linear part of the curve.

The correction factor ($\frac{K\tau}{T}$) can thus be calculated from the equation if values of the intercepts c are taken from the experimental curve. In practice, however, it was found rather difficult to draw the tangents accurately enough, with the result that large errors occurred in the estimation of the intercepts, and hence in the value obtained for the correction factor.

A better method is to use the linear portion of the curve to obtain $(\frac{\mu}{\rho})$ and then to calculate $(\frac{K \tau}{T})$ by means of equation (3.16) for each individual foil measurement.

The equation gives us

$$\omega(\frac{\mu}{\rho}) = \log_{e} R + \frac{K\tau}{T}M$$

$$(\frac{\mu}{\rho}) = \frac{\log_{e} R}{\omega} + \frac{1}{\omega}\frac{K\tau}{T}M$$

$$= (\frac{\mu}{\rho})_{obs} + \frac{1}{\omega}\frac{K\tau}{T}M$$

where $\left(\frac{\mu}{\rho}\right)_{obs} = \frac{1}{\omega} \log_e R$.

Hence

$$\frac{\mathbf{K}\tau}{\mathbf{T}} = \omega \left[\left(\frac{\mu}{\rho}\right) - \left(\frac{\mu}{\rho}\right)_{\text{obs}} \right] / \mathbb{M}$$
 -----(3.21)

For each individual foil ω , both $\left(\frac{\mu}{\rho}\right)_{obs}$ and M are calculated from the observed counts. Then, using the value of $\left(\frac{\mu}{\rho}\right)$ obtained by taking the slope of the linear part of the curve, $\left(\frac{K \cdot \tau}{T}\right)$ is calculated from equation (3.21) for each measurement. Because of the statistical nature of the counting data, large differences occur between the individual values, but the mean is fairly accurate, and is taken as the correct value - the degree of accuracy being determined by a calculation of the probable error by the method of residuals.

We may note here, that once $\left(\frac{K}{T}\right)$ has been determined for any particular wavelength, the value can then be used to correct all subsequent measurements carried out with that wavelength - care being taken to operate the X-ray tube at the same voltage and current each time.

(a) Preliminary work.

For this work the monochromator was fitted with the silver reflector, and a copper target inserted in the X-ray tube. The whole apparatus was then set up and adjusted as described in Part 2, Section 6, of this thesis, and a preliminary series of readings, (shown in table 3.6), taken with aluminium foils in order to

TABLE 3.6.

| x(cms) | No | N | N. | Nº | М | log R | Mean \log_{10} R |
|---------|------|------|------|------|------|--------|-----------------------|
| | 1515 | 280 | 2461 | 2556 | 1330 | 0.7496 | |
| .0132 | 1337 | 253 | 2061 | 2281 | 1304 | 0.7671 | 0.7421 |
| | 1416 | 268 | 2226 | 2159 | 1081 | 0.7095 | and the second second |
| | 1519 | 643 | 1735 | 1793 | 934 | 0.3867 | enjäge over 1 |
| .0068 | 1165 | 499 | 1560 | 1571 | 677 | 0.3714 | 0.3849 |
| | 1366 | 639 | 1485 | 1733 | 975 | 0.3968 | |
| A CO | 1494 | 745 | 1775 | 1674 | 648 | 0.2768 | |
| .0048 | 1966 | 1131 | 2317 | 2173 | 691 | 0.2267 | 0.2426 |
| | 1918 | 1175 | 2547 | 2615 | 801 | 0.2244 | |
| f. | 1701 | 1224 | 2199 | 2185 | 463 | 0.1401 | - En en y |
| .0030 | 1694 | 1215 | 2291 | 2314 | 502 | 0.1598 | 0.1495 |
| | 1714 | 1220 | 2268 | 2273 | 399 | 0.1494 | and and a |
| iş şəri | 1839 | 1331 | 2373 | 2333 | 468 | 0.1308 | a wan |
| .0026 | 1775 | 1329 | 2317 | 2370 | 499 | 0.1357 | 0.1310 |
| 11- | 1842 | 1385 | 2299 | 2314 | 472 | 0.1265 | |
| 1 | 1743 | 1355 | 2344 | 2438 | 494 | 0.1264 | Saliche e si sè |
| .0027 | 1883 | 1355 | 2367 | 2367 | 528 | 0.1430 | 0.1443 |
| | 1643 | 1127 | 2130 | 2150 | 536 | 0.1678 | |

Test series with Aluminium foils

3.4.



check the purity of the monochromatic beam and obtain the correction for lost counts.

Three counting runs were taken with each of six foils of different thicknesses, the mean value of $\log_{10} R$ being computed for each foil.

First of all, $\log_{10} R$ was plotted against the foil thickness, x to give the curve shown in fig (3.3). The slope of the linear part of the curve gives

$(\frac{\mu}{\rho}) = 49.30$

which agrees quite well with the accepted value for Aluminium at the Cu K α_1 wavelength. Further, the curve also shows that the beam is not contaminated by any other wavelengths , since it does not bend in such a way as to give a positive intercept on the $\log_{10} R$ axis when the linear portion is extrapolated to x = 0.

We have in this case, however, a slight negative intercept, which is (as discussed In Part 3, Section 3,(d) due to counting losses.

In table (3.7), $(\frac{K\tau}{T})$ has been calculated from each individual counting measurement by means of equation (3.21) using $(\frac{\mu}{\rho}) = 49.30$ as the correct value of the mass absorption coefficient.

We may mention here, that the large differences between the individual values are due to the inherent statistical variations of the counts. A definite positive mean value is obtained, however, which thus definitely establishes the presence of counting losses in the system. In order to calculate the probable error of the mean value the residuals of $\frac{K\tau}{T}$ and their squares are also given in the table.

| | A DAY | | 6 | - | the second states of the secon | and the second se | |
|------------------------------------|------------|------|-------------------------------|---|--|---|---|
| GMS/ SQ CM | (H) OBS | M | $\frac{M}{co} \times 10^{-4}$ | $(\overset{\mu}{\rho})$ - $(\overset{\mu}{\rho})_{OBS}$ | $\frac{\kappa\tau}{\tau} \times 10^6$ | $\frac{K\tau}{T} - \frac{K\tau}{T}$ | $\left(\frac{K\tau}{T} - \frac{\overline{K\tau}}{T}\right)^2$ |
| بلي هي مي | 42.90 | 468 | 6.664 | 6.40 | 96.03 | + 24.65 | 608 |
| .00702 | 44.51 | 499 | 7.106 | 4.79 | 67.39 | - 3.99 | 16 |
| | 41.50 | 472 | 6.721 | 7.80 | 116.06 | + 44.62 | 1991 |
| | 39.93 | 494 | 6.774 | 9.37 | 138.32 | + 66.92 | 4479 |
| .00729 | 45.16 | 528 | 7.241 | 4.14 | 57.18 | - 14.20 | 202 |
| | 53.00 | 536 | 7.351 | -3.70 | - 50.32 | -121.70 | 14810 |
| | 39.85 | 463 | 5.716 | 9.45 | 165.33 | + 93.92 | 8821 |
| .00810 | 47.90 | 502 | 6.197 | 1.40 | 22,59 | - 48.79 | 2380 |
| eg e ³ Contra e esta | 42.50 | 399 | 4.926 | 6.80 | 138.04 | + 66.62 | 4439 |
| nilon ^{der} die die Ne | 49.19 | 648 | 4.999 | 0.11 | 2.20 | - 69.18 | 4786 |
| .01296 | 40.29 | 691 | 5.331 | 9.01 | 169.01 | + 97.62 | 9530 |
| | 39.87 | 801 | 6.119 | 9.43 | 152.61 | + 81.22 | 6596 |
| e e geodreaneg og g | 48.51 | 934 | 5.086 | 0.79 | 15.53 | - 55.85 | 3120 |
| .01836 | 46.59 | 677 | 3.687 | 2.71 | 73.51 | + 2.13 | 4 |
| | 49.77 | 975 | 5.310 | -0.47 | - 8.85 | - 80,23 | 6437 |
| a de la come | 48,44 | 1330 | 3.732 | 0.86 | 23,05 | - 48.33 | 2336 |
| .03565 | 49.57 | 1304 | 3,658 | -0.27 | - 7.38 | - 78.76 | 6203 |
| | 45.83 | 1081 | 3.033 | 3.47 | 114,41 | + 43.02 | 1851 |

Calculation of $\left(\frac{K\tau}{m}\right)$ for Cu Ka, radiation

The final value obtained for the correction factor is then

 $\frac{K\tau}{T}$ = (71 ± 11) X 10⁻⁶

In order to correct experimental values of log , R we require

 $\frac{1}{2.3026} \left(\frac{K\tau}{T}\right) \text{ which is } (31 \pm 5) \times 10^{-6}$

This value is now used to correct all subsequent measurements carried out with this wavelength - care being taken to keep the tube voltage and current at the same values throughout.



FIG. 3.5

POSITION 2. Near the counter window.



(b) Experimental technique.

The absorption measurements

were carried out with the foils placed in the monochromatic beam in two different positions, as follows

POSITION 1.....Between the two slits of the collimating system. (fig 3.4)

In this position, only the transmitted X-ray beam is detected by the counter, the fluorescent and scattered X-rays not coming through the second slit, so that the measurements obtained with this arrangement give the real total absorption coefficients, $(\frac{\mu}{\rho})$.

POSITION 2..... Near the counter window. (fig 3.5)

In this second position, some fluorescent and scattered X-rays, as well as the main transmitted beam enter the counter, giving a slightly increased transmitted intensity which should therefore give a smaller value of $\left(\frac{\mu}{\rho}\right)$. In the rest of this work, this absorption coefficient will be denoted by $\left(\frac{\mu}{\rho}\right)'$.

For each metal, three foils of different thicknesses were used, and three counting runs were taken with each foil in both positions. Each counting run consisted of five consecutive counting periods of three minutes duration, and were carried out as described in Part 3, Section 3 (b). $\log_{10} R$ was then calculated for each counting run, corrected for counting losses, and the mass absorption coefficient determined. Nine values of $(\frac{\mu}{\rho})$ and $(\frac{\mu}{\rho})'$ were thus obtained.

The results, using Beryllium foils, are given in table (3.8) as a typical example of the procedure.

Cu Ka, radiation

Beryllium (1.82 gms/cc)

Example of the experimental procedure.

| | | | P O | SIT | O I 9 | N 1 | | | | | | 1 | P (|) S I | TI | ON 2 | 3 | | |
|----------|----------------|-----|------|------|-------|---------------------|--------|-------------------------|---------------------------------|----------|------|-----|------|-------|------|---------------------|----------------|------------------------------|----------------------------------|
| x cms | N _° | N | N, | M , | M | log _{io} R | C(M) | log ₀ R +C(≝) | $\left(\frac{\mu}{\rho}\right)$ | x cms | N | N | N°, | N 8 | 詞 | log _{io} R | G (M) | log ₁₀ R +C(M) | $\left(\frac{\mu}{\rho}\right)'$ |
| | 1853 | 414 | 2291 | 2310 | 1458 | 0.6545 | .04374 | 0.6982 | 1,990 | | 1365 | 286 | 2123 | 2174 | 1130 | 0.6891 | .0 3390 | 0.7230 | 2.060 |
| 0.444 | 1809 | 394 | 2259 | 2286 | 1442 | 0.6671 | .04326 | 0.7004 | 1.998 | 0.444 | 1314 | 268 | 2098 | 2163 | 1111 | 0.7038 | .03333 | 0.7371 | 2,101 |
| | 2115 | 503 | 2575 | 2653 | 1690 | 0.6366 | .05070 | 0.6873 | 1.959 | | 1269 | 230 | 2176 | 2058 | 1157 | 0.6176 | .03471 | 0.6523 | 1.859 |
| | 1861 | 934 | 2299 | 2377 | 1005 | 0.3139 | .03015 | 0.3441 | 2.204 | | 1310 | 631 | 2235 | 2087 | 531 | 0.2876 | .01.593 | 0.3035 | 1.944 |
| 0.1975 | 1721 | 912 | 2190 | 2200 | 819 | 0.2777 | .02457 | 0,3023 | 1.936 | 0.1975 | 1299 | 654 | 2143 | 2327 | 829 | 0.3339 | .02487 | 0.3588 | 2.299 |
| 2.6 | 1959 | 911 | 2392 | 2260 | 416 | 0.3078 | .01248 | 0.3203 | 2.051 | | 1376 | 656 | 2250 | 2159 | 620 | 0.3037 | .01860 | 0.3223 | 2.064 |
| | 1829 | 792 | 2423 | 2440 | 1054 | 0.3665 | .03162 | 0.3981 | 2.239 | | 1521 | 685 | 2484 | 2507 | 859 | 0.3503 | .02577 | 0.3761 | 2.115 |
| 0.2250 | 1895 | 802 | 2598 | 2539 | 1034 | 0.3634 | .03102 | 0.3944 | 2.218 | 0.2250 | 1554 | 654 | 2586 | 2643 | 957 | 0.3853 | .02871 | 0.4140 | 2.328 |
| | 1803 | 789 | 2375 | 2466 | 1105 | 0.3753 | .03315 | 0.4085 | 2.297 | | 1510 | 661 | 2635 | 2600 | 814 | 0.3530 | .02442 | 0.3774 | 2.122 |

66

(c) Results.

Nine metals in all were examined with Cu K α_1 radiation, both $(\frac{\mu}{\rho})$ and $(\frac{\mu}{\rho})'$ being measured.

The results are given in tables (3.9---- to 3.17) where in each case, the values obtained with different foil thicknesses are tabulated, together with their deviations from the mean value, in order to show the variations due to counting statistics and between individual foils.

The probable error in the mean value of each mass absorption coefficient is calculated from the square of the residuals, which are given in the last column of each table.

BERYLLIUM.

P = 1.82 gms/cc.

| | 1.420 | POSITION | 1 | POSITION 2 | | | | | |
|---------|--------|--|---|-----------------|---------|---|--|--|--|
| x | i di p | $\frac{\mu}{\rho} - \overline{\frac{\mu}{\rho}}$ | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ | <u>μ</u> ' ρ | #'- #p' | $\left(\frac{\mu}{\rho}' - \overline{\frac{\mu}{\rho}'}\right)^2$ | | | |
| | 1,990 | -0.109 | .01188 | 2.060 | -0.039 | .00152 | | | |
| 0.4440 | 1,998 | -0.101 | .01020 | 2.101 | -0.002 | .00000 | | | |
| 8 2 M M | 1.959 | -0.140 | .01960 | 1.859 | -0.240 | .05760 | | | |
| | 2.204 | -0.105 | .01103 | 1.944 | -0.155 | .02403 | | | |
| 0.1975 | 1.936 | -0.163 | .02657 | 2.299 | -0.200 | .04000 | | | |
| | 2.051 | -0.048 | .00230 | 2.064 | -0.035 | .00123 | | | |
| | 2.239 | -0.140 | .01960 | 2.115 | -0.016 | .00026 | | | |
| 0.2250 | 2.218 | -0.119 | .01416 | 2,328 | -0.229 | .05244 | | | |
| | 2.297 | -0.198 | .03960 | 2,122 | -0,023 | .00053 | | | |

Absorption of Cu K_{α_1} radiation

| | S. K. G. B. 15. S | THE REPORT OF | |
|---------|---|---------------|-------|
| | A increase in the second se | μp | μ' |
| Mean va | lue | 2.099 | 2.099 |
| Standar | d deviation | 0.046 | 0.049 |
| Probabl | e error | 0.031 | 0.033 |

 $\frac{(\mu)}{\beta} = 2.10 \pm .03$

 $\left(\frac{\mu}{\rho}\right)' = 2.10 \pm .03$

CARBON

P = 1.52 gms/cc

| | · F | OSITION | 1 | I | OSITION | 2 |
|--|--------------------|--|---|---------------------|--|---|
| x cms | $\frac{\mu}{\rho}$ | $\frac{\mu}{\overline{\rho}} - \overline{\frac{\mu}{\overline{\rho}}}$ | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ | $\frac{\mu'}{\rho}$ | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| - 1 2. 1. | 4.303 | -0.156 | .02434 | 4.441 | -0.042 | .00176 |
| 0.2852 | 4.323 | -0.136 | .01850 | 4.522 | +0.039 | .00152 |
| | 4.598 | +0.139 | .01932 | 4.543 | +0.060 | .00360 |
| а (<u>6</u> . т. 4 . К | 4.764 | +0.305 | .09303 | 4.783 | +0.300 | .09000 |
| 0.1800 | 4.590 | +0,131 | .01716 | 4.365 | -0.118 | .01392 |
| 15 M | 4.358 | -0.101 | .01020 | 4.077 | -0.406 | .16484 |
| 2- 44 H | 5.007 | +0.548 | .30030 | 4.950 | +0.467 | .21809 |
| 0.0551 | 4.424 | -0.035 | .00123 | 4.685 | +0.202 | .04080 |
| an a | 3.762 | -0.697 | .48580 | 3.979 | -0.504 | .25402 |

Absorption of Cu K a, radiation

| | <u>n</u> | $\frac{\mu}{\rho}$ |
|--------------------|----------|--------------------|
| Mean value | 4.459 | 4.483 |
| Standard deviation | 0.116 | 0.105 |
| Probable error | 0.078 | 0.071 |

 $\left(\frac{\mu}{\rho}\right) = 4.46 \pm .08$

 $\left(\frac{\mu}{\rho}\right)' = 4.48 \pm .07$

ALUMINIUM

ġ.

 $\rho = 2.7 \text{ gms/cc}$

| Absorption | of | Cu | Ka, | radiation | 1 |
|------------|----|----|-----|-----------|---|
|------------|----|----|-----|-----------|---|

| | , | OSITION | POSITION 2 | | | |
|---|--------------------|--|---|--------------------|---|---|
| x cms | $\frac{\mu}{\rho}$ | $\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}$ | $\left(\frac{\mu}{\overline{\rho}} - \frac{\overline{\mu}}{\overline{\rho}}\right)^2$ | $\frac{\mu}{\rho}$ | $\frac{\mu'}{\rho} - \frac{\mu'}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| $= - \frac{1}{2} \cdot m = - \frac{1}{2} \cdot \frac{1}{2}$ | 51.01 | +1.42 | 2.016 | 47.59 | +0.55 | 0.303 |
| 0.0132 | 52.08 | +2,49 | 6.200 | 51.91 | +4.87 | 23.717 |
| 1000 - 10000 - 10000 - 1000 - 1000 - 1000 - 1000 - 1000 - 1000 - 1000 - | 47.93 | -1.66 | 2.756 | 44.63 | -2,41 | 5.808 |
| 1.1.1 | 52.01 | +2,42 | 5.856 | 42.60 | -4.44 | 19.714 |
| 0.0068 | 49.13 | -0.46 | 0,212 | 54.20 | +7.16 | 51.266 |
| | 53.45 | +3,86 | 14.900 | 48.16 | +1.12 | 1.254 |
| | 52.64 | +3.05 | 9,303 | 43.94 | -3,10 | 9,610 |
| 0.0048 | 43.96 | -5.63 | 31.700 | 45.53 | -1.51 | 2.280 |
| 1 | 44.15 | -5.44 | 29.594 | 44.75 | -2.29 | 5.244 |

| | Щ Р | μ' |
|--------------------|--------|-------|
| Mean value | 49.59 | 47.04 |
| Standard deviation | 1.19 | 1.29 |
| Probable error | 0.80 | 0.87 |

 $\left(\frac{\mu}{\rho}\right)$ 49.6 ± 0.8 -

 $\left(\frac{\mu}{\rho}\right) = 47.0 \pm 0.9$

TABLE 3,12

IRON

P = 7.8 gms/ec

| | I | OSITION | Jl | PC | DSITION | 2 |
|----------|--------|---------------------------------------|--|-------|--|---|
| x cms | μ ρ | $\frac{\mu}{\rho} - \frac{\mu}{\rho}$ | $\left(\frac{\mu}{\rho}-\frac{\mu}{\rho}\right)^2$ | H'P | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu}{\rho}' - \frac{\overline{\mu}}{\rho}'\right)^2$ |
| Sec. 1 | 318.6 | +10.1 | 102.01 | 301.1 | + 0.2 | 0.0 |
| .000623 | 294.3 | -14.2 | 201.64 | 293.2 | - 7.7 | 59.3 |
| | 307.3 | - 1.2 | 1.44 | 303.9 | + 3.0 | 9.0 |
| | 284.6 | -23.9 | 571.21 | 285.1 | -15.8 | 249.6 |
| .000876 | 303.6 | - 4.9 | 24.01 | 275.7 | -25.2 | 635.0 |
| | 319.8 | +11.3 | 127.69 | 277.0 | -23.9 | 571.2 |
| | 318.1 | + 9.6 | 92.16 | 316.2 | +15.3 | 234.1 |
| .001010 | 314.8 | + 6.3 | 39.69 | 321.6 | +20.7 | 428.5 |
| | 315.1 | + 6.6 | 43.56 | 334.2 | +33.3 | 1109.0 |

Absorption of Cu K α , radiation

| | $\frac{\mu}{2}$ | <u><u> </u></u> |
|--------------------|-----------------|-----------------|
| Mean value | 308.5 | 300.9 |
| Standard deviation | 4.1 | 6.8 |
| Probable error | 2.8 | 4.6 |

 $\left(\frac{\mu}{\rho}\right) = 309 \pm 3$

 $\left(\frac{\mu}{\rho}\right) = 301 \pm 5$

NICKEL

 $\rho = 8.9 \text{ gms/cc}$

| William R. R. | 1.7 × - 1 / - 1 / - | | | li | | 1. A. | |
|--|---------------------|---------|---|-------------------------|--|---|--|
| 1 | a constant I | POSITIO | N l | POSITION 2 | | 2 | |
| x cms | <u>щ</u> Р | H - H | $\left(\frac{\mu}{\overline{\rho}} - \frac{\overline{\mu}}{\overline{\rho}}\right)^2$ | <u><u>µ</u>' P'</u> | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)$ | |
| 1. ¹ . 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. | 49.51 | -3,82 | 14.59 | 58.91 | + 6.79 | 46.10 | |
| .000900 | 54.30 | +0.97 | 0.94 | 41.90 | -10.22 | 104.45 | |
| | 53.50 | +0.17 | 0.03 | 44.71 | - 7.41 | 54.91 | |
| | 50.18 | -3.15 | 9.92 | 68.50 | | | |
| .001800 | 50.54 | -2.79 | 7.78 | 55.59 | + 3.47 | 12.04 | |
| | 52.26 | -1.07 | 1.15 | 53.46 | + 1.34 | 1.80 | |
| | 57.61 | +4.28 | 18.32 | 56.44 | + 4.32 | 18,66 | |
| .002700 | 53.54 | +0.21 | 0.04 | 51.38 | - 0.74 | 0.55 | |
| | 58.53 | +5.20 | 27.04 | 54.54 | + 2.42 | 5.86 | |

Absorption of Cu Ka, radiation

*Neglected when taking mean

| | μ p | <u><u><u></u><u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u></u></u></u> |
|--------------------|--------|---|
| Mean value | 53.33 | 52.12 |
| Standard deviation | 1.05 | 1.84 |
| Probable error | 0.71 | 1.24 |

 $\left(\frac{\mu}{\rho}\right) = 53.3 \pm 0.7$

 $\left(\frac{\mu}{\rho}\right) = 52.1 \pm 1.2$

72

COPPER

$\rho = 8.89 \text{ gms/cc}$

53.8 + 0.7

Absorption of Cu K α , radiation

| | PO | SITION | 1 | POSITION 2 | | |
|----------|---------------|--|---|--------------------|--|---|
| x cms | <u>u</u> p | $\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}$ | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ | $\frac{\mu}{\rho}$ | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| | 48.66 | -2.12 | 4.49 | 57.04 | +3.20 | 10.24 |
| .002283 | 53.15 | +2.37 | 5.62 | 53.06 | -0.78 | 0.61 |
| | 50.05 | -0.73 | 0.53 | 50.66 | -3.18 | 10.11 |
| 49 1 | 45.94 | -4.84 | 23.43 | 58.94 | +5.10 | 26.01 |
| .001010 | 50.12 | -0.66 | 0.44 | 53.81 | -0.03 | 0.00 |
| | 52.75 | +1.97 | 3.88 | 51.22 | -2,62 | 6.86 |
| | 52.08 | +1.30 | 1.69 | 57.16 | +3.32 | 11.02 |
| .002765 | 50.73 | -0.05 | 0.00 | 51.97 | +1.87 | 3.50 |
| | 53.54 | +2.76 | 7.62 | 51.74 | -2.10 | 4.41 |

| an gerrar in the term | μp | $\frac{\mu}{\rho}$ |
|-----------------------|-------|--------------------|
| Mean value | 50.78 | 53,84 |
| Standard deviation | 0.81 | 1.01 |
| Frobable | 0.55 | 0.68 |

 $\left(\frac{\mu}{\rho}\right)$ 50.8 + 0.6

ZINC

P = 7.1 gms/cc

| Absorption | OL | 210 | Do al | T.SUTSICTON |
|------------|----|-----|-------|-------------|
| | | | 100 | |

| POSITION 1 | | | POSITION 2 | | | |
|------------|-------|-------------------|---|----------------------|---------------|---|
| x cms | щ | μ <u>-</u> μ φ | $\left(\frac{\mu}{\rho}-\frac{\overline{\mu}}{\rho}\right)^2$ | $\frac{\mu}{\rho}$ ' | <u>щ'- щ'</u> | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| | 65.63 | +5.19 | 26.94 | 55,95 | -3,23 | 10.43 |
| .00080 | 57.61 | -2,83 | 8.01 | 58.21 | -0.97 | 0.94 |
| | 53,80 | -6.64 | 44.09 | 57.61 | -1.57 | 2.47 |
| | 36,55 | * | * | 58,41 | -0.77 | 0,59 |
| .00160 | 44,32 | * | | 61.11 | +1.93 | 3.73 |
| | 56,50 | -3,94 | 15,52 | 59,60 | +0,42 | 0.18 |
| | 67.86 | +7.42 | 55.06 | 61.08 | +1.90 | 3.61 |
| .00240 | 61.27 | +0.83 | 0.69 | 61.04 | +1.86 | 3.46 |
| | 60.43 | -0.01 | 0.00 | 59,60 | +0.42 | 0.18 |

*Neglected when taking mean

| | <u>µ</u> | $\frac{\mu}{\rho}'$ |
|--------------------|----------|---------------------|
| Mean value | 60,44 | 59.18 |
| Standard deviation | 1.90 | 0.06 |
| Probable error | 1.28 | 0.04 |

 $\frac{(\mu)}{(\rho)} = 60.4 \pm 1.3$

 $\left(\frac{\mu}{\rho}\right)' = 59.2 \pm 0.0$

74

MOLYBDENUM

 $\rho = 9.01 \text{ gms} / cc$

| | P | POSITION 1 | | | POSITION 2 | | |
|----------|-------|------------|--|------------|------------|---|--|
| x cms | 4p | 4- atp | $\left(\frac{\mu}{\rho}-\frac{\mu}{\rho}\right)^{2}$ | <i>µ</i> ' | Hp-Hp | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ | |
| | 162.4 | +4.3 | 18.49 | 152.3 | + 1.6 | 2,56 | |
| .000672 | 164.9 | +6.8 | 46.24 | 159.6 | + 8.9 | 79.21 | |
| | 155.2 | -2.7 | 7.29 | 166.8 | +16.1 | 259.2 | |
| | 157.9 | -0.2 | 0.04 | 146.4 | - 4.3 | 18,49 | |
| .000906 | 153.7 | -4.4 | 19.36 | 135.1 | * | | |
| | 162.8 | +4.7 | 22.09 | 141.8 | - 8.9 | 78.21 | |
| | 158.0 | -0.1 | OL | 157.2 | + 6.5 | 42.25 | |
| .001541 | 157.5 | -0.6 | .36 | 144.9 | - 5,8 | 33,64 | |
| | 150.1 | -8.0 | 64.00 | 156.7 | + 6.0 | 36.00 | |

Absorption of Cu K α_1 radiation

* Neglected when taking mean

| | μ | <u><u></u> <u>μ</u>'</u> |
|--------------------|-------|--------------------------|
| Mean value | 158.1 | 150.7 |
| Standard deviation | 1.6 | 2.8 |
| Frobable error | 1.1 | 1.9 |

(H) ≝ 158 ± 1

<u>- 151 +</u> 2 (舟)

PALLADIUM

$\rho = 12.2 \text{ gms/cc}$

| | P | OSITION | 1 | POSITION 2 | | |
|----------|-------------------------|-------------------------|---|-------------------------|--|---|
| x cms | <u>щ</u> | # - # | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ | $\frac{\mu}{\rho}$ | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| .000552 | 208.1 195.4 206.3 | +16.2 + 3.5 +14.4 | 262.4 12.25 207.4 | 213.9 207.0 228.1 | - 4.6 + 2.3 +18.8 | 21.16 5.29 353.4 |
| .001026 | 178.6 175.3 181.6 | 13.3 16.6 10.3 | 176.9 275.6 106.1 | 198.9 213.5 195.2 | -10:4 +4:2 -14:1 | 108.2 17.64 198.8 |
| .001064 | 206.2 186.5 188.9 | +14.3 - 5.4 - 3.0 | 204.5 29.16 9.00 | 210.0 207.2 209.9 | + 0.7 | 0.49 4.41 0.36 |

Absorption of Cu Ka, radiation

| | <u>µ</u> p | $\frac{\mu}{\rho}$ |
|---------------------|---------------|--------------------|
| Mean value | 191.9 | 209.3 |
| Standard deviation. | 4.2 | 3.1 |
| Probable error | 2.9 | 2.1 |

p) 192 + 3

 $\left(\frac{\mu}{\rho}\right) = 209 \pm 2$
To end this Section the mass absorption coefficients obtained with Cu K α_1 radiation, are summarised in tables (3.18) and (3.19). The mean percentage probable error of the measurements is found to be 1.5 %.

TABLE 3.18

| TOTAL MASS ABSORPTION COEFFICIENTS (+) | | | | | | | |
|--|----|------------------|------------------------|-------------------|---------------------|--|--|
| Absorber | | Atomic number | Absorption coefficient | Probable error | % Probable error | | |
| Beryllium | Be | 4 | 2.10 | <u>+</u> 0.03 | 1.5 | | |
| Carbon | С | 6 | 4.46 | <u>+</u> 0.08 | 1.7 | | |
| Aluminium | Al | 13 | 49.6 | <u>+</u> 0.8 | 1.6 | | |
| Iron | Fe | 26 | 309 | <u>+</u> 3 | 0.9 | | |
| Nickel | Nİ | 28 | 53.3 | + 0.7 | 1.3 | | |
| Copper | Cu | 29 | 50.8 | <u>+</u> 0.6 | 1.2 | | |
| Zine | Zn | 30 | 60.4 | <u>+</u> 1.3 | 2.1 | | |
| Molybdenum | Mo | 42 | 158 | <u>+</u> 1 | 0.7 | | |
| Palladium | Pđ | 46 | 192 | <u>+</u> 3 | 1.5 | | |

TOTAL MASS ABSORPTION COEFFICIENTS $(\frac{\mu}{2})$

TABLE 3.19

| Absorber | | Atomic number | Absorption coefficient | Probable error | % Probable error |
|------------|----|------------------|------------------------|-------------------|---------------------|
| Beryllium | Be | 4 | 2.10 | <u>+</u> 0.03 | 1.5 |
| Carbon | ģ | 6 | 4.48 | <u>+</u> 0.07 | 1.9 |
| Aluminium | Al | 13 | 47.0 | <u>+</u> 0.9 | 1.8 |
| Iron | Fe | 26 | 301 | <u>+</u> 5 | 1.3 |
| Nickel | Ni | 28 | 52.1 | <u>+</u> 1.2 | 2.4 |
| Copper | Cu | 29 | 53.8 | + 0.7 | 1.3 |
| Zinc | Zn | 30 | 59.2 | <u>+</u> 0.04 | 0.08 |
| Molybdenum | Mo | 42 | 151 | + 2 | 1.2 |
| Palladium | Pd | 46 | 209 | + 2 | 1.0 |

MASS ABSORPTION COEFFICIENTS $\left(\frac{\mu}{\rho}\right)$

(a) Freliminary work.

For this work, a Cobalt target was inserted in the X-ray tube in place of the Copper one, the rest of the apparatus being left undisturbed since the silver reflector in the monochromator reflected the Co K α_1 radiation along exactly the same path as taken by the Cu K α_1 beam

TABLE 3.20

| x cms | N, | N | N. | M . | M | log _{io} R | Mean log ₁₀ R |
|------------------|------|------|------|------|------|---------------------|-----------------------------|
| | 3265 | 2078 | 4232 | 4253 | 1229 | 0.2012 | |
| .0026 | 3453 | 2197 | 4074 | 4056 | 1274 | 0.1945 | 0.1960 |
| | 2796 | 1882 | 2723 | 2856 | 1046 | 0.1923 | |
| | 3617 | 2226 | 3909 | 3868 | 1349 | 0.2060 | 1.4 |
| .0027 | 3624 | 2231 | 3872 | 3982 | 1503 | 0,2229 | 0,2132 |
| | 3433 | 2156 | 3980 | 4061 | 1358 | 0.2108 | |
| | 2534 | 1506 | 3205 | 3366 | 1190 | 0.2436 | |
| .0033 | 3462 | 2080 | 4785 | 4753 | 1378 | 0.2220 | 0.2452 |
| 16 | 3626 | 2100 | 4199 | 4513 | 1855 | 0.2701 | |
| | 3441 | 1174 | 4628 | 3972 | 1611 | 0.3907 | |
| .0048 | 3127 | 1341 | 3703 | 3881 | 1964 | 0.3882 | 0,3718 |
| | 4050 | 1860 | 4675 | 4659 | 2174 | 0.3365 | |
| | 3990 | 1100 | 4328 | 4305 | 2867 | 0.5573 | |
| .0068 | 4065 | 1157 | 4431 | 4624 | 3101 | 0.5642 | 0.5551 |
| | 4138 | 1206 | 4698 | 4788 | 3022 | 0,5437 | |
| ж. ²⁹ | 2915 | 210 | 3357 | 3356 | 2704 | 1.1550 | |
| .0132 | 3145 | 286 | 3618 | 3753 | 2994 | 1.0570 | 1.0940 |
| | 3231 | 271 | 3113 | 3660 | 2907 | 1.0701 | |

Test series with Aluminium foils

3.5



TABLE 3,21

| GMS/SQ CM | (HL) DBS | м | M/ _∞ × 10 ⁶ | (些)-(世) 035 | <u>Κ</u> τ×10 ⁶ | $\frac{KT}{T} - \frac{KT}{T}$ | $\begin{pmatrix} KT - KT \\ T & T \end{pmatrix}$ |
|------------|-------------|------|-----------------------------------|----------------|----------------------------|-------------------------------|--|
| 14. S. | 66.00 | 1229 | 0.1750 | 8.03 | 45.88 | - 1.25 | 2 |
| .00702 | 63,80 | 1274 | 0.1813 | 10.23 | 56.41 | + 9.28 | 86 |
| | 63.10 | 1046 | 0.1490 | 10.93 | 73.35 | +26.22 | 688 |
| | 65.07 | 1349 | 0.1850 | 8.96 | 48.43 | + 1.30 | 2 |
| .00729 | 68,80 | 1503 | 0.2061 | 5.23 | 25.37 | -21.76 | 474 |
| | 66.57 | 1358 | 0.1863 | 7.46 | 40.04 | - 7.09 | 50 |
| | 63.96 | 1190 | 0.1335 | 10.07 | 75.40 | +28.27 | 799 |
| .00891 | 57.38 | 1378 | 0.1558 | 16.65 | 106.90 | +59.77 | 3572 |
| | 69.91 | 1855 | 0.2117 | 4,12 | 19.46 | -27.67 | 766 |
| | 69.43 | 1611 | 0.1243 | 4.61 | 37.09 | -10.04 | 101 |
| .01296 | 68.97 | 1964 | 0.1524 | 5.07 | 33.28 | -13.85 | 192 |
| n den | 59.80 | 2174 | 0.1678 | 14.24 | 84.85 | +37.72 | 1423 |
|) | 69.90 | 2867 | 0.1567 | 4.14 | 26,42 | -20.71 | 430 |
| .01836 | 70.78 | 3101 | 0.1689 | 3.26 | 19.30 | -27.83 | 774 |
| a. 1946 | 68.20 | 3022 | 0.1649 | 5.84 | 35,42 | -11.71 | 137 |
| | 74.63 | 2704 | 0.0759 | -0,59 | -7.78 | -54.91 | 3015 |
| .03565 | 68.30 | 2994 | 0.0840 | 5.74 | 68.33 | +21.20 | 449 |
| 76.9 | 69.13 | 2907 | 0.0815 | 4.91 | 60.21 | +14.08 | 198 |

Calculation of $\left(\frac{KT}{T}\right)$ for Co Ka, radiation

in the previous work.

The same procedure was adopted, and a preliminary series of readings taken with Aluminium foils to check the purity of the beam and obtain the correction for lost counts. These test results are given in tables (3.20) and (3.21) and by the graph shown in fig (3.6). They indicate a pure monochromatic beam of Co K α , radiation, and a correction factor $\frac{1}{2.3026} \left(\frac{KT}{T}\right)$ equal to (20.5 ± 1.9) X 10⁻⁶.

(b) Results. These are given in tables (3.22) ... to ... (3.30)

BERYLLIUM.

Absorption of Co Ka, radiation.

| | F | OSITION | 1 | POSITION 2 | | |
|----------|--------|--|---|--------------------|--|---|
| x Cms | μ P | $\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}$ | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ | $\frac{\mu}{\rho}$ | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ |
| | 2.064 | ~0.307 | .09425 | 2,195 | -0.213 | .04537 |
| 0.4440 | 1.884 | -0.487 | .23717 | 2,218 | -0.190 | .03610 |
| | 2.054 | -0.317 | .10050 | 2.163 | -0.245 | .06003 |
| | 2,471 | +0.100 | .01000 | 2,339 | -0.069 | .00476 |
| 0,1975 | 2.419 | +0.048 | .00230 | 2.169 | -0,239 | .05712 |
| | 2,388 | +0.017 | .00029 | 2.160 | -0.248 | .06150 |
| | 2,581 | +0.210 | .04410 | 2.729 | +0.321 | .10304 |
| 0.2250 | 2.827 | +0.456 | .20794 | 2.990 | +0.582 | ,33872 |
| | 2.653 | +0.282 | .07952 | 2.707 | +0.299 | .08940 |

| | <u>µ</u> p | ju' |
|--------------------|---------------|-------|
| Mean value | 2,371 | 2,408 |
| Standard deviation | 0.104 | 0.105 |
| Probable error | 0.072 | 0.071 |

2.37 + .07

(#) = 2.41 ± .07

CARBON

9.53

San Donego

The search

 $\rho = 1.52 \text{ gms/ec}$

Absorption of Co K a, radiation

| т. н. (| 200 | POSITION | 1 | PC | SITION | 2 |
|------------|-------|----------|---|---------|--|---|
| x cms | щp | | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ | μ' P | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| * 21.1 | 7.191 | -0.017 | .00029 | 6,739 | -0.297 | .08821 |
| 0.1800 | 6.650 | -0,558 | .31136 | 7.121 | +0.085 | .00723 |
| | 6.993 | -0.215 | .04623 | 7.205 | +0.169 | .02856 |
| | 7.476 | +0,268 | .07182 | 6.943 | -0.093 | •00865 |
| 0.0728 | 6.853 | -0,355 | .12602 | 6.294 | -0.742 | .55056 |
| ŧ | 7.428 | +0.220 | .04840 | 6.644 | -0.392 | .15366 |
| | 7.158 | -0,050 | .00250 | 7.870 | +0.834 | .69555 |
| 0.0551 | 7.951 | +0.743 | •55205 | 7.323 | +0.287 | .08237 |
| 1 | 7.175 | -0.033 | .00109 | 7.188 | +0.152 | .02310 |

| | μp | मू ' |
|--------------------|-------|-------|
| Mean value | 7.208 | 7.036 |
| Standard deviation | 0.127 | 0.151 |
| Probable error | 0.086 | 0.102 |

 $\left(\frac{\mu}{\rho}\right) = 7.21 \pm .09$

 $\left(\frac{\mu}{\rho}\right)' = 7.04 \pm .10$

81

ALUMINIUM

$\rho = 2.7 \, \text{gms/cc}$

Absorption of Co Ka, radiation

| | PC | SITION | 1 | POSITION 2 | | |
|----------|--------|--|--|-----------------|--|---|
| x Cms | μ ρ | $\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}$ | $\left(\frac{\mu}{\rho}-\frac{\mu}{\rho}\right)^{2}$ | <u>µ</u> ' P | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| | 78.17 | + 3.27 | 10.692 | 76.83 | + 4.60 | 21.160 |
| 0.0132 | 72.21 | - 2.69 | 7.236 | 74.48 | + 2.25 | 5.063 |
| Coleya * | 73.01 | - 1.89 | 3.572 | 75.28 | + 3.05 | 9.303 |
| | 77.27 | + 2.37 | 5.617 | 70.66 | - 1.57 | 2.465 |
| 0.0068 | 78.39 | + 3.49 | 12.180 | 72.78 | + 0.55 | 0.303 |
| | 75.97 | + 1.07 | 1.145 | 73.41 | + 1.18 | 1.392 |
| | 75.28 | + 0,38 | 0.144 | 69.70 | - 2.53 | 6.401 |
| 0.0048 | 76.11 | + 1.21 | 1.464 | 69.71 | ~ 2.52 | 6.350 |
| | 67.70 | - 7.20 | 51.840 | 67.21 | - 5.02 | 25.200 |

| | 1 P | µ' ₽ |
|--------------------|--------|---------|
| Mean value | 74.90 | 72.23 |
| Standard deviation | 1.14 | 1.04 |
| Probable error | 0.77 | 0.70 |

 $\left(\frac{\mu}{\rho}\right)$ 74.9 ± 0.8

 $\left(\frac{\mu}{\rho}\right) = 72.2 \pm 0.7$

IRON

 $\rho = 7.8 \text{ gms/ec}$

| | POSITION 1 | | | POSITION 2 | | |
|--------------------------------------|--------------------|--|---|------------|--|---|
| x CMS | $\frac{\mu}{\rho}$ | $\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}$ | $\left(\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}\right)^2$ | Ц Р | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)$ |
| 1 | 51.67 | - 3,39 | 11.490 | 54.05 | - 0.65 | 0.42 |
| .001320 | 52.80 | - 2.26 | 5.180 | 59.71 | + 5.01 | 25,10 |
| - faz- | 55.20 | + 0.14 | 0.020 | 54.91 | + 0.21 | 0.04 |
| 5.45 2.57 2.57 2.57 2.57 | 59.77 | + 4.71 | 22,180 | 59.73 | + 5.03 | 25.30 |
| .001010 | 54.86 | - 0.20 | 0.040 | 58,98 | + 4.20 | 17.64 |
| | 54.68 | - 0.38 | 0,144 | 56.25 | 41.55 | 2.40 |
| | 55.61 | + 0.55 | 0,303 | 47.87 | - 6.83 | 46.65 |
| .000876 | 56.84 | + 1.78 | 3.168 | 50.06 | - 4.64 | 21.53 |
| | 54.11 | - 0.95 | 0.903 | 50.75 | - 3,85 | 14.82 |

Absorption of Co K α_1 radiation

| | μ | $\frac{\mu}{\rho}$ |
|--------------------|-------|--------------------|
| Mean value | 55.06 | 54.70 |
| Standard deviation | 0.70 | 1.46 |
| Probable error | 0.47 | 0.99 |

 $\left(\frac{\mu}{\rho}\right) = 55.1 \pm 0.5$

 $\left(\frac{\mu}{\rho}\right)' = 54.7 \pm 1.0$

NICKEL

 $\rho = 8.9 \text{ gms} / \text{ce}$

| | PC | DSITION | 1 | POSITION 2 | | |
|----------|---------------|--|--|-----------------|---------------|---|
| X CMS | <u>µ</u> p | $\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}$ | $\left(\frac{\mu}{\rho} - \frac{\mu}{\rho}\right)^2$ | <u>ሥ</u> ' የ | <u>μ'-</u> μ' | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| | 69.11 | - 4.87 | 23.72 | 69.83 | - 5.48 | 30.03 |
| .000900 | 78.70 | + 4.72 | 22,28 | 83,33 | + 8,02 | 64.32 |
| | 79.80 | + 5.82 | 33.87 | 83.67 | + 8.36 | 69,89 |
| | 71.36 | - 2.62 | 6.86 | 77.01 | + 1.70 | 2,89 |
| .001800 | 61.94 | -12.04 | 145.00 | 79,99 | 4.68 | 21.90 |
| - * * | 64.49 | - 9.04 | 81.72 | 76.37 | + 1.06 | 1.12 |
| | 80.35 | + 6.37 | 40.58 | 71.96 | - 3,35 | 11,22 |
| .002700 | 86.49 | +12.47 | 155,50 | 67.20 | - 8.11 | 65.77 |
| | 73.73 | - 0.27 | 0.07 | 68,43 | - 6.88 | 47.33 |

Absorption of Co Ka, radiation

| | | 节 | щ' |
|--------|--------------|-------|-------|
| Mean v | alue | 73.98 | 75.31 |
| Standa | rd deviation | 2,66 | 2,02 |
| Probab | le error | 1.80 | 1.37 |

74.0 ± 1.8 (H) -

75.3 ± 1.4 P

COPPER

1-1 = 10

040

-

P = 8.89 gms / cc

| | P | OSITION | 1 | POSITION 2 | | |
|----------------|--------------------|--|---|---------------------|---|--|
| x ems | $\frac{\mu}{\rho}$ | $\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}$ | $\left(\frac{\mu}{\rho}-\frac{\overline{\mu}}{\rho}\right)^2$ | $\frac{\mu'}{\rho}$ | $\frac{\mu'}{\rho} - \frac{\mu'}{\rho}$ | $\left \left(\frac{\mu'}{\overline{\rho}} - \frac{\overline{\mu'}}{\overline{\rho}} \right)^2 \right $ |
| 1. 6 10 | 88.80 | +13,02 | 169.5 | 79.07 | + 3.83 | 14.67 |
| .002283 | 81.19 | + 5.41 | 29.27 | 81.02 | + 5.78 | 33,41 |
| | 79,69 | + 3.91 | 15,29 | 78.30 | + 3,06 | 9.36 |
| | 75.18 | - 0.60 | 0,36 | 64.83 | -10,41 | 108.40 |
| .001010 | 69,21 | - 6.57 | 43.16 | 71.11 | - 4.13 | 17.06 |
| × 5* | 79.27 | + 3,49 | 12,18 | 74.03 | - 1.21 | 1.46 |
| | 72.61 | - 3,17 | 10.05 | 77.93 | + 2,65 | 7.24 |
| .002765 | 69.21 | - 6.57 | 43,16 | 76.21 | + 0.97 | 0.94 |
| E I I | 66.87 | - 8.91 | 79.39 | 74.71 | - 0.53 | 0.28 |

6,7

Absorption of Co Ka, radiation

| Ī | т. т. | n P | M/P |
|----|--------------------|--------|-------|
| | Mean value | .75.78 | 75.24 |
| 14 | Standard deviation | , 2,36 | 11.65 |
| | Probable error | 1.60 | 1.11 |

· .

$$\left(\frac{\mu}{\rho}\right) = 75.8 \pm 1.6$$

 $\left(\frac{\mu}{\rho}\right)' = 75.2 \pm 1.1$

ZINC

P = 7.1 gms / cc

Absorption of Co Ka, radiation

| | P(| DSITION | 1 | POSITION 2 | | |
|---------------------|--------------------|---------|---|---------------------|--|---|
| X CMS | $\frac{\mu}{\rho}$ | H - H P | $\left(\frac{\mu}{\overline{\rho}}-\frac{\overline{\mu}}{\overline{\rho}}\right)^2$ | $\frac{\mu'}{\rho}$ | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| | 83,85 | - 0,52 | 0,27 | 80.03 | - 8.06 | 64.96 |
| .00080 | 79.29 | - 5.08 | 25.81 | 95,92 | + 7.83 | 61.31 |
| | 82,50 | - 1.87 | 3,50 | 81,63 | - 6.46 | 41.73 |
| ngessi • The con | 86.07 | + 1.70 | 2.89 | 90,58 | + 2.49 | 6.20 |
| .00160 | 92.01 | + 7.64 | 58.37 | 97.84 | + 9.75 | 95.06 |
| | 78,83 | - 5.54 | 30,69 | 101.4 | +13.31 | 177.20 |
| | 85.51 | + 1.14 | 1.30 | 81.01 | - 7.08 | 50.13 |
| .00240 | 86.10 | + 1.73 | 2.99 | 84,87 | - 3,22 | 10.37 |
| | 85,15 | + 0,78 | 0.61 | 79.51 | - 8,58 | 73.62 |

| | $\frac{\mu}{\rho}$ | $\frac{\mu}{\rho}$ |
|--------------------|--------------------|--------------------|
| Mean value | 84.37 | 88,09 |
| Standard deviation | 1,33 | 2,97 |
| Probable error | 0,89 | 2.01 |

$$\left(\frac{\mu}{\rho}\right) = 84.4 \pm 0.9$$

 $\left(\frac{\mu}{\rho}\right)' = 88.1 \pm 2.0$

MOLYBDENUM

P = 9.01 gms / cc

Absorption of Co Kc, radiation

| | POS | SITION | 1 | POSITION 2 | | |
|----------|--------------------|--------|---|--------------------|--|---|
| x Cms | $\frac{\mu}{\rho}$ | M- HP | $\left(\frac{\mu}{\rho}-\frac{\overline{\mu}}{\rho}\right)^2$ | $\frac{\mu}{\rho}$ | $\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}$ | $\left(\frac{\mu'}{\overline{\rho}} - \frac{\overline{\mu'}}{\overline{\rho}}\right)^2$ |
| | 200.6 | -14.9 | 222.0 | 209.4 | - 0.6 | 0.4 |
| .000627 | 205.6 | - 9.9 | 98,0 | 199.0 | -11.0 | 121.0 |
| | 218.8 | + 3.3 | 10.9 | 225.3 | +15.3 | 234.1 |
| | 214.1 | - 1.4 | 1.9 | 198,4 | -11.6 | 134.6 |
| .000906 | 218,2 | + 2.7 | 7.3 | 172.4 | * | |
| | 198.1 | -17.4 | 302.8 | 203.2 | - 6.8 | 46.2 |
| | 219,1 | + 3.6 | 13.0 | 217.3 | + 7.3 | 53.3 |
| .001368 | 234.1 | +18.8 | 353.4 | 211.0 | + 1.0 | 1.0 |
| | 231.8 | +16.3 | 265.7 | 216.7 | + 6.7 | 44.9 |

* Neglected when taking mean

| | HP P | 1 pl |
|--------------------|---------|-------|
| Mean value | 215.5 | 210.0 |
| Standard deviation | 4.2 | 3,4 |
| Probable error | 2.8 | 2.3 |

$$\left(\frac{\mu}{\rho}\right) = 216 \stackrel{+}{=} 3$$

 $\left(\frac{\mu}{\rho}\right)' = 210 \pm 2$

87

PALLADIUM

P = 12.2 gms / cc

Absorption of Co K &, radiation

| | P | DSITION | 1 | POSITION 2 | | |
|------------|--------------------|--|---|---------------------|--------|---|
| x cms | $\frac{\mu}{\rho}$ | $\frac{\mu}{\rho} - \frac{\overline{\mu}}{\rho}$ | $\left(\frac{\mu}{\rho}-\frac{\overline{\mu}}{\rho}\right)^2$ | $\frac{\mu'}{\rho}$ | | $\left(\frac{\mu'}{\rho} - \frac{\overline{\mu'}}{\rho}\right)^2$ |
| | 324.5 | + 36.0 | 1296.0 | 296.9 | - 5,3 | 28.1 |
| .000552 | 308.4 | + 19.9 | 396.0 | 311.9 | + 9.7 | 94.1 |
| | 293.1 | + 4.6 | 21.2 | 290.0 | - 12.2 | 148.9 |
| | 265.6 | - 22.9 | 524.4 | 276.2 | - 26.0 | 676.0 |
| .001026 | 276.9 | - 11.6 | 134.6 | 308.7 | + 6.5 | 42,3 |
| e e dika y | 297.6 | + 9.1 | 82.3 | 313.6 | + 11.4 | 130.0 |
| * | 268.7 | - 19.8 | 392.0 | 315.2 | + 13.0 | 169.0 |
| .001064 | 287.5 | - 1.0 | 1.0 | 279.6 | - 22.6 | 510.8 |
| | 274.2 | - 14.3 | 204.5 | 328.0 | + 25.8 | 665.6 |

| | $\frac{\mu}{\rho}$ | $\frac{\mu}{\rho}$ |
|--------------------|--------------------|--------------------|
| Mean value | 288,5 | 302.2 |
| Standard deviation | 6.5 | 5.7 |
| Probable error | 4.4 | 3.9 |

$$\left(\frac{\mu}{\rho}\right) = 289 \div 4$$

The mass absorption coefficients obtained with Co K α , wavelength are summarised and given in tables (3.31) and (3.32). The mean percentage probable error of the measurements is 1.6 %.

TABLE 3.31

IMY

| Absorber | | Atomic number | Absorption coefficient | Probable error | % Probable error |
|------------|----|------------------|------------------------|-------------------|---------------------|
| Beryllium | Be | 4 | 2.37 | ± 0.07 | 3.0 |
| Carbon | C | 6 | 7.21 | ± 0.09 | 1.2 |
| Aluminium | Al | 13 | 74.9 | ± 0.8 | 1.2 |
| Iron | Fe | 26 | 55.1 | ± 0.5 | 0.9 |
| Nickel | Ni | 28 | 74.0 | ± 1.8 | 2.4 |
| Copper | Cu | 29 | 75.8 | ± 1.6 | 2.1 |
| Zine | Zn | 30 | 84.4 | ± 0,9 | 1.1 |
| Molybdenum | Mo | 42 | 216 | ± 3 | 1.3 |
| Palladium | Pd | 46 | 289 | ± 4 | 1.5 |

TABLE 3.32

| Absorber | + × * | Atomic | Absorption coefficient | Probable e rror | % Probable error | |
|--------------------|-------|--------|------------------------|---------------------------|---------------------|--|
| Beryllium | Be | 4 | 2.41 | ± 0.07 | 2.9 | |
| Carbon | С | 6 | 7.04 | ± 0.10 | 1.4 | |
| Aluminium | Al | 13 | 72.2 | ± 0.7 | 1.0 | |
| Iron | Fe | 26 | 54.7 | ± 1.0 | 1.8 | |
| Nickel | Ni | 28 | 75.3 | ± 1.4 | 1.8 | |
| Copper | Cu | 29 | 75.2 | ± 1.1 | 1.5 | |
| Zinc | Zn | 30 | 88.1 | ± 2.0 | 2.3 | |
| Molybdenum | Mo | 42 | 210 | ± 2 | 1.1- | |
| Pa lladiu m | Pd | 46 | 302 | ± 4 | 1.3 | |

MASS ABSORPTION COEFFICIENTS $\left(\frac{\mu}{\rho}\right)'$

COMPARISON OF THE TWO MEASURED MASS ABSORPTION COEFFICIENTS

$\left(\frac{\mu}{\rho}\right)$ AND $\left(\frac{\mu}{\rho}\right)'$

The mass absorption coefficients of nine metals were measured for Cu K α , and Co K α , radiation, by mounting the absorbing foils in two different positions in the X-ray beam, to give $(\frac{\mu}{\rho})$ and $(\frac{\mu}{\rho})'$ respectively. In the first position, only the unabsorbed transmitted beam enters the counter, while in the second, some scattered X-rays should also be collected. The difference between the two values should therefore give us an indication of the amount of scattering that occurs during the absorption process.

Values of $(\frac{\mu}{\rho} - \frac{\mu}{\rho}')$ deduced from the results obtained with Cu K α , and Co K α , radiation, are given in tables (3.33) and (3.34) respectively.

In nearly every case, a positive or negative value of

TABLE 3.33

| Element | | Atomic number | $\left(\frac{\mu}{\rho}\right) = \left(\frac{\mu}{\rho}\right)'$ | Probable error | |
|------------|----|------------------|--|-------------------|--|
| Beryllium | Be | 4 | 0.00 | ± 0.05 | |
| Carbon | c | 6 | - 0.02 | ± 0.12 | |
| Aluminium | Al | 13 | + 2.6 | ± 1.1 | |
| Iron | Fe | 26 | + 7.6 | ± 5 . 3 | |
| Nickel | Ni | 28 | + 1.2 | ± 1.4 | |
| Copper | Cu | 29 | - 3.1 | ± 1.4 | |
| Zinc | Zn | 30 | + 1.3 | ± 1.3 | |
| Molybderum | Mo | 42 | + 7.4 | ± 2.2 | |
| Palladium | Pd | 46 | -17.4 | ± 3.6 | |

Cu K a, RADIATION

3.6

| Element | - 1 - 1 | Atomic number | $\left(\frac{\mu}{\rho}\right) = \left(\frac{\mu}{\rho}\right)'$ | Probable error |
|------------|---------|------------------|--|-------------------|
| Beryllium | Be | 4 | - 0.04 | ± 0.10 |
| Carbon | C | 6 | + 0.17 | ± 0.13 |
| Aluminium | Al | 13 | + 2.7 | ± 1.0 |
| Iron | Fe | 26 | + 0.4 | ± 1.1 |
| Nickel | Ni | 28 | - 1.3 | ± 2,3 |
| Copper | Cu | 29 | + 0.5 | ± 2.0 |
| Zine | Zn | 30 | - 3.7 | - 2.2 |
| Molybdenum | Mo | 42 | + 5.5 | ± 3.6 |
| Palladium | Pa | 46 | -13.7 | ± 5.8 |

Co Ka, RADIATION

the same magnitude as the probable error of the result is obtained, which leads us to conclude that, at these two wavelengths and for the metals considered, we obtain within the experimental error of the measurement the same mass absorption coefficient value irrespective of whether the foils are placed in Position 1 or 2.

This means that the portion of the scattered X-rays collected by the counter when the foils are in the second position, is too small to be detected in a measurement of the transmitted intensity since it is of the same magnitude as the experimental error of the measurement.

This is explained by the fact that only the X-rays scattered through a small solid angle in the forward direction reach the sensitive region of the counter, all the X-rays scattered at other angles being undetected, so that a large fraction of the total scattered is not measured. Further, at these wavelengths, even if all the scattered X-rays leaving the specimen are collected and measured by means of suitable apparatus, it would not give a true picture of the scattering process, because the fluorescent absorption is relatively high and a large proportion of the scattered rays would be absorbed before they leave the specimen.

As the wavelength of the radiation decreases, the fluorescent absorption becomes smaller and smaller, so that the scattering of the X-rays becomes more and more important. However, even at these short wavelengths, direct measurement of $^{6}/_{\rho}$ is very difficult, because elaborate corrections for the self-absorption of the scattered rays by the scatterers themselves, have to be carried out.

92



FIG 3.7

93

(a) Preliminary work.

For these experiments a Chromium plated target was inserted in the X-ray tube, and the monochromator initially fitted with an Aluminium reflector. When the collimating slits and Geiger counters were then aligned to receive the best possible beam from the monochromator, it was found to be rather weak for absorption measurements, and so the Aluminium reflector was replaced by Tantalum, which gave a more intense reflected beam.

Some preliminary measurements with Aluminium foils gave a $\log_{10} I/I$ against ω curve of the form shown in fig (3.7), which for small thicknesses has a slope, changing continuously, instead of being constant as is required for a pure monochromatic beam. This indicates that the beam contains some other wavelengths as well as the Cr K α , probably arising from the white radiation produced by the X-ray tube. An attempt was made to eliminate them by working the tube at a lower voltage, but this also decreased the intensity of the required wavelength so much that accurate log, I/I, measurements were difficult to obtain. Further, all attempts to filter out the unwanted wavelengths were unsuccessful, because they are far more penetrating than the Cr K α , wavelength. In fact, the Cr K α , radiation is attenuated 50 % in passing through 20 cms of air, while shorter wavelengths are hardly affected. This means that, even if there is only 1 % of short wavelengths present in the beam leaving the monochromator, it has increased to 20 % by the time the beam arrives at the

counter.

Because of these difficulties, it was decided to use the beam without any modification and attempt to obtain the absorption coefficients by graphical analysis of the intensity against thickness curves.

(b) Measurement of mass absorption coefficients with beams containing more than one wavelength.

Suppose the X-ray beam contains a number of wavelengths $\lambda_1, \lambda_2, \lambda_3$the fraction of the total intensity of the beam due to each wavelength being $\alpha_1, \alpha_2, \alpha_3$, as detected by the Geiger counter. Then the total intensity I_o of the heterogeneous beam is made up of α_1 , α_2 , α_3 on.

If the mass absorption coefficients of the absorbing material at these wavelengths are $\left(\frac{\mu}{\rho}\right)_{2}$, $\left(\frac{\mu}{\rho}\right)_{2}$, $\left(\frac{\mu}{\rho}\right)_{3}$, etc then the intensity I transmitted through a foil of thickness ω is given by

Now, on physical grounds, it is apparent that when ω is large, the transmitted beam will contain only the most penetrating wavelength that was present in the initial beam, the more readily absorbed radiations having been filtered out by the absorbing material.

Suppose that in equation (3.22) we have written the





terms in the order of decreasing penetrating power, that is, $(\frac{\mu}{\rho})_{_{l}} < (\frac{\mu}{\rho})_{_{2}} < (\frac{\mu}{\rho})_{_{3}} \quad \dots \quad \lambda_{_{1}}$ being the most penetrating wavelength, $\lambda_{_{2}}$ the next, and so on.

The equation can then be written

 $\frac{I}{I_{o}} = e^{-\left(\frac{\mu}{\rho}\right)_{1}\omega} \left[\alpha_{1} + \alpha_{2}e^{-\left\{\left(\frac{\mu}{\rho}\right)_{2} - \left(\frac{\mu}{\rho}\right)_{1}\right\}\omega + \alpha_{3}\dots}\right]$

so that

$$\log_{10}\left(\frac{\mathbf{I}}{\mathbf{I}_{o}}\right) = \frac{-\left(\frac{\mu}{\rho}\right)_{i}\omega}{2.3026} + \log_{10}\left[\alpha_{i} + \alpha_{2}e + \cdots\right]$$

(3.23)

The essential shape of this " transmission curve " is shown in fig (3.8). The straight line gives the form of the curve if all the radiations were of wavelength .

It is seen that at large values of ω the curve becomes parallel to the straight line and is given by

 $\log_{10}\left(\frac{I}{I_{o}}\right) = -\left(\frac{\mu}{\rho}\right)_{1} \omega / 2.3026 + \log_{10}\left(\alpha_{1}\right)$

the slope of which gives us $(\frac{\mu}{\rho})_{i}$ and the intercept on the $\log_{10}(I/I_{\circ})$ axis, $\log_{10}(\alpha_{i})$. The mass absorption coefficient at wavelength and the fractional intensity due to this wavelength can thus be determined.

Fig (3.9) shows some calculated transmission curves for an X-ray beam containing two wavelengths when they are present in different amounts. It shows that quite large departures from the ideal linear relationship obtained with pure monochromatic beams are possible, and that the curves always bend away from the $\log_{10}(1/I_{\odot})$ axis. It should thus be possible to analyse an observed transmission curve by the method just described and obtain the percentages



of the different wavelengths present and their associated mass absorption coefficients reasonably accurately. This would be carried out as follows :-

(1) Experimentally determined values of I_{I_o} are plotted against ω , and from the curve a graph of $\log_{0.0}(I_{I_o})$ against ω computed.

(2) $\left(\frac{\mu}{\rho}\right)$ and α for the most penetrating wavelength are then obtained as already explained. Let them be $\left(\frac{\mu}{\rho}\right)$ and $\alpha_{1,2}$

(3) The component $\alpha_i e^{-\left(\frac{\mu}{\rho}\right)_i \omega}$ is then drawn on the I_{I_0} diagram and subtracted from the observed transmission curve to give another curve which is due to all the wave-lengths except λ_i . The equation of this modified curve will then be

 $\frac{I}{I_{o}} = \alpha_{2}e^{-\left(\frac{\mu}{\rho}\right)_{2}\omega} + \alpha_{3}e^{-\left(\frac{\mu}{\rho}\right)_{3}\omega} + \dots$

(4) Transfer of this curve on to the $\log_{10}(1/1_{)})$ diagram will then give

$$\log_{10}\left(\frac{I}{I_{o}}\right) = \frac{-\left(\frac{\mu}{\rho}\right)_{2}\omega}{2.3026} + \log_{10}\left[\alpha_{2} + \alpha_{3}e^{-\left\{\left(\frac{\mu}{\rho}\right)_{3} - \left(\frac{\mu}{\rho}\right)_{2}\right\}\omega} + \cdots\right]$$

from which another component α_2 and $(\frac{\mu}{\rho})_2$ can be determined as before.

In the present investigation, a straight line is generally obtained here, which means that there are no more components to consider.

However, if the curve obtained is not linear, the component $\alpha_2 e^{-(\frac{\mu}{\rho})_2^{\omega}}$ is now drawn on the I/I_0 diagram and subtracted from the modified curve to leave, this time a transmission curve due to all the wavelengths except

 λ_1 and λ_2 .

(5) This is then transferred on to the $\log_{10}(I/I_{\circ})$ diagram and α_3 , $(\frac{\mu}{\rho})_3$ determined, and so on.

Proceeding in this way the complete curve is analysed into its component wavelengths, the fractional intensity α and mass absorption coefficient $(\frac{\mu}{\rho})$ for each component being determined.

(c) Counting Loss Corrections.

In this case the previous method used to calculate the correction factor $\frac{K\Upsilon}{T}$ is not applicable, because now, the departure from the ideal linear log₁₀ R against ω curve is not only due to the correcting term $\left(\frac{K\Upsilon}{T}\right)$ M, but also due to the wavelength composition of the X-ray beam. The effective absorption coefficient now varies with the thickness ω in a manner depending on the combination of wavelengths present in the X-ray beam.

For one particular foil thickness, however, the absorption coefficient (and hence $\log_{10} R$) is constant, so that any variations observed when $\log_{10} R$ is measured for various values of N_0 will be entirely due to counting losses. Further, if the measured values of $\log_{10} R$ are plotted against ($N_0 - N$) the best curve through the points is given by

 $\left(\frac{\mu}{\rho}\right)\omega = 2.3026 \log_{10} R + \frac{KT}{T} (N_o - N)$

where $(\frac{\mu}{\rho})\omega$ is a constant. This is a straight line of slope $(-\frac{1}{2.3026}\frac{K\tau}{T})$ and gives therefore the correction factor.



The results obtained by using an Aluminium foil of thickness (0.0132 cm) are shown in table (3.35) and by the graph (fig 3.10).

| N, | N | (N N) | log, R | | |
|------|-----|-------|--------|--|--|
| 1214 | 173 | 1041 | 0.8467 | | |
| 1099 | 160 | 939 | 0.8318 | | |
| 1082 | 161 | 921 | 0.8278 | | |
| 912 | 130 | 782 | 0.8450 | | |
| 729 | 100 | 629 | 0.8642 | | |
| 726 | 109 | 617 | 0.8223 | | |
| 587 | 86 | 501 | 0.8340 | | |

TABLE 3.35

During these measurements the X-ray output was kept as steady as possible and N_o varied by altering the width of the first slit of the collimator. It can be stated here, that it is not admissible to vary N_o by changing the tube voltage, or by inserting filters in the primary beam because this would also change the wavelength composition and hence $(\frac{\mu}{\rho})$ for the foil.

Since the correction factor $\frac{K}{T}$ is small in this case, it is difficult to ascertain the exact slope of the $\log_{10} R$ against (N_o - N) graph, because it is nearly completely masked by the inherent statistical variations of the counting measurements. The results, however, do indicate an approximate value of (15 X 10⁵) for the correction factor, and show that it is small enough to be neglected in comparison with the statistical differences of individual measurements, especially when we consider that the absorption coefficients are to be obtained in this case by graphical analysis, and will therefore not be so accurate as the previous measurements.

(d) Results.

Transmission curves were obtained for the passage of the heterogeneous beam through thin foils of Beryllium, Carbon, Aluminium, Iron, Nickel, Copper, Zinc Molybdemum and Palladium, and in discussing the results, it will be advantageous to divide them into three groups namely

- (1) Those of the light substances (Be, C, and Al) whose absorption lies wholly in the K-series.
- (2) Those elements whose absorptions lie wholly in the L-series. (Zn, Mo, and Pd)
 - (3) Elements whose absorptions lie partly in the K and partly in the L-series. (Ni, Cu, and Fe)

(1) Group 1. Beryllium, Carbon, and Aluminium.

The three graphs, figs (3.11), (3.12), and (3.13) give the $I_{I_{i}}$ and $\log_{i_{i}}(I_{I_{i}})$ curves obtained with each of these elements respectively, together with the components into which they are resolved by the method of analysis just described.

In each case, two components (one hard and one soft) are obtained, each being present in approximately the same amount (50 %). The two mass absorption coefficients and the percentage of each component wavelength in the main







beam, obtained with the three absorbers, are given in table (3.36)

TABLE 3.36

| Element | | Long wavelength | | Short wavelength | |
|-----------|----|-----------------|---------------------------------|------------------|--------------|
| | | % | $\left(\frac{\mu}{\rho}\right)$ | % | (<u>#</u>) |
| Beryllium | Be | 50.0 | 4.51 | 49.0 | 1.27 |
| Carbon | C | 49.0 | 13.4 | 49.6 | 2.99 |
| Aluminium | Al | 52,5 | 165 | 49.0 | 31.7 |

Mean = 50.5 % Mean = 49.2 %

A. A. A. A. A. A. A.

A comparison of the mass absorption coefficients with the usually accepted values indicates that the long wavelength is the Cr K α_i as expected, while the shorter wavelength is 1.360 kX units.

(2) Group 2. Zinc, Molybdenum, and Palladium.

and we do not show the first of

The results

obtained with these three metals are shown on the graphs figs (3.14), (3.15), and (3.16). As before, the results in each case indicate one hard and one soft wavelength as the main component of the Chromium beam.

| TABLE | з. | 37 |
|-------|----|----|
|-------|----|----|

| Element | | Long wavelength | | Short wavelength | |
|------------|----|-----------------|-----|------------------|--------------|
| | | % | (声) | % | (<u>μ</u>) |
| Zine | Zn | 49.0 | 159 | 51.9 | 39 |
| Molybdenum | Mo | 50.1 | 455 | 50.1 | 181 |
| Palladium | Pd | 48.9 | 572 | 49.9 | 150 |

Mean = 49.3% Mean = 50.6%

100







A comparison of the results with the usually accepted values again indicates that one component of the beam is the Cr K α , wavelength, while the other is a shorter wavelength, 1.360 kX units, each making up 50 % of the total beam. In the case of Palladium, only a rough value of the absorption coefficient for the second component could be obtained, since foils < 0.006 gms/sq cm, could not be produced to give experimental points on the curve between A and B (fig 3.16). In this case, $(\frac{\mu}{\rho})$ is calculated from the points A and B only, and the portion of the curve between A and B deduced from it so that an idea of the complete curve can be obtained.

(3) Group 3. Iron, Nickel, and Copper.

so far, indicate the presence of two wavelengths (namely the Cr K α , and L.360 kX) in the composite beam, and that for the metals examined, the shorter wavelength is always the most penetrating. This does not necessarily follow for the metals in this group, because we now have a K absorption edge between the two wavelengths, so that either one can be the most penetrating, as shown in the diagram fig (3.17).

The results, taken

Again, wavelengths which were not detected before might now show up. The graphs, figs (3.18), (3.19), and (3.20) give the I/I_o and $\log_o(I/I_o)$ curves obtained with Iron, Nickel, and Copper respectively, together with the components into which they resolve. In each case, the two main components are Cr Ka, and 1.360 kX as before, but in the case of Iron, the Cr Ka, is the most penetrating radiation




CASE 1. The longer wavelength being the most

FIG. 3.17

1 1 -







2

18 N

as opposed to the shorter wavelength in the other two cases.

A trace of another wavelength component is indicated by Iron and Nickel, but with Iron the curve is not sufficiently accurate at small values of ω for the corresponding absorption coefficient to be determined.

Table (3.38) gives the mass absorption coefficients and the percentage of each component wavelength in the beam, obtained for the three absorbers.

TABLE 3.38

Fe, Ni, and Cu.

| 1997 - 196 1 | Long wa | velength | Short wa | welength | Other wavelengths | |
|-----------------|----------------------|----------|---------------------------------|----------|---------------------------------|--------|
| e grande i | $(\frac{\mu}{\rho})$ | % | $\left(\frac{\mu}{\rho}\right)$ | % | $\left(\frac{\mu}{\rho}\right)$ | : % |
| Iron | 106 | 54.9 | 258 | 35.5 | . <u>-</u> 1 | 8.5 |
| Nickel | 146 | 41.7 | 290 | 16.4 | 45.8 | 16.4 |
| Copper | 152 | 60.3 | 38.5 | 41.7 | | 1 a |

These results seem to indicate that the short wavelength in the beam really consists of a small band of wavelengths, ranging from $1.2 \rightarrow 1.7$ kX units. A mean value of the absorption coefficient over this band is obtained for the metals which have no critical absorption edge in this region, because the method of graphical analysis is not sufficiently accurate to resolve the band into its components.

When measurements are carried out, however, on a

metal which has its K critical absorption edge within this small band of wavelengths, the difference between the absorption coefficient each side of the edge, is sufficient for two components to be detected, which, together with the Cr K α , give three components for the whole curve.

TABLE 3.39

| Absorber | r i | 1.360 kX | Cr Ka, | | |
|------------|-----|----------|--------|--|--|
| Beryllium | Be | 1.27 | 4.51 | | |
| Carbon | C | 2.99 | 13.4 | | |
| Aluminium | Al | 31.7 | 165 | | |
| Iron | Fe | 258 | 106 | | |
| Nickel | N1 | 290 | 146 | | |
| Copper | Cu | 38.5 | 152 | | |
| Zinc | Zn | 39.0 | 159 | | |
| Molybdenum | Mo | 121 | 455 | | |
| Palladium | Pd | 150 | 572 | | |

MASS ABSORPTION COEFFICIENTS

In the above table (3.39), the values of the absorption coefficients obtained with Chromium radiation are given.

PART 4

4.1. COMPARISON OF THE PRESENT MASS ABSORPTION COEFFICIENTS

WITH VALUES OBTAINED BY OTHER INVESTIGATORS.

In tables (4.1), (4.2), (4.3), and (4.4) the measured mass absorption coefficients are compared with the values obtained by some other investigators.

Since very few actually measured values can be found for these elements at the wavelengths considered here, table values from Internationale Tabellen zur Bestimmung von Kristallstrukturen (1935) Vol.2, page 575, are also included.

TABLE 4.1.

| | Andrews | Allen | Grosskurth | Laubert | Martin & Lang | From Tables | Present Work |
|------------------------|-----------|--------|-------------|------------|--|----------------|-----------------|
| Be | 4.87 | | | | 1.1.1.1.1.1 | 1.35 | 2.10 |
| C | 4.87 | 4.9 | | | and the second | 5.50 | 4.46 |
| Al | 49.7 | 48.5 | 51.15 | | 1.1 | 48.7 | 49.6 |
| Fe | | 330 | | | 327 | 324 | 309 |
| Ni | | 47.5 | 50.01 | 49.25 | 47.3 | 49.3 | 53.3 |
| Cu | 50.0 | 50 | 51.25 | 51.49 | 49.4 | 52.7 | 50.8 |
| Zn | n er Su S | 59 | h n' cat- | | 58.3 | 59.0 | 60.4 |
| Mo | | | and a grant | real tests | | 164 | 158 |
| Pd | | | | | a Alexandra da seriesta da se | 207 | 192 |
| $\frac{1}{\lambda kX}$ | 1.5386 | 1.5386 | 1,5386 | 1.5386 | 1.5386 | 1.542 | 1.5374 |

Comparison of $(\frac{\mu}{\rho})$ for Cu Ka, radiation with values given by other observers.

TABLE 4.2.

| | Andrews | Allen | Grosskurth | Laubert | From Tables | Present Work |
|-----|------------|----------------|------------|---------|----------------|-----------------|
| Be | 5.04 | | | | 2.42 | 2,37 |
| C | | 7.3 | | | 8.50 | 7.21 |
| Al | | 74.2 | 76.34 | | 73.4 | 74.9 |
| Fe | | 56 | | | 59.5 | 55.1 |
| Ni | | 69 | 72.59 | 72.68 | 75.1 | 74.0 |
| Cu | rana Talay | 76 | | 77.70 | 79.8 | 75.8 |
| Zn | | 90 | | | 88.5 | 84.4 |
| Mo | | e se s | | | 242 | 216 |
| Pd | · · · · · | n age ta Se | | | 308 | 289 |
| λkX | 1.753 | 1.752 | 1.7866 | 1.7866 | 1.790 | 1.7853 |

Comparison of $(\frac{\mu}{\rho})$ for Co K α , radiation

TABLE 4.3

Comparison of $(\frac{\mu}{\rho})$ for Cr Ka, radiation

with values given by other observers.

| | Andrews | Allen | Grosskurth | Biermann | From Tables | Present Work |
|-----|---------------|-------|--|----------|----------------|-----------------|
| Ве | | | | | 4.74 | 4.51 |
| С | 15.5 | 14.7 | | | 17.9 | 13.4 |
| Al | 153 | 148 | 151.9 | 152.3 | 149 | 165 |
| Fe | in s Gar | 113 | | | 115 | 106 |
| Ni | | 142 | ne sense to to to popular La constante de la constante de | | 145 | 146 |
| Cu | 155 | 156 | hu waxaya digi w | 에게 가지? | 154 | 152 |
| Zn | | 182 | | | 169 | 159 |
| Mo | | | | | 439 | 455 |
| Pd | n e ster of f | 時気気が | endu El manny La | | 545 | 572 |
| λkX | 2.285 | 2.24 | 2,2863 | 2.2863 | 2.291 | 2.285 |

TABLE 4.4

| | Grosskurth | Laubert | Allen | Laubert | Allen | *From Tables | Present Work |
|-----|---|-----------|------------|---|------------------------|-----------------|-----------------|
| Be | | | | | - 4 - 3 ^{- 4} | 0.75 | 1.27 |
| c | 3,52 | | 3.80 | | 3.2 | 3.4 | 2.99 |
| Al | | | 36.0 | a state for | 29.8 | 34 | 31.7 |
| Fe | $\mathcal{C}(\mathcal{G}_{n}(X_{n})) = \{1, \dots, n\}$ | Spectra M | | n ing i gi | 213 | 240 | 258 |
| NL | in dia manjarah | 305.3 | 1.1.3 1.51 | 253.3 | 237 | 275 | 290 |
| Cu | 41.6 | 41.4 | 38.0 | 252.8 | 266 | 35 | 38.5 |
| Zn | | ing da ta | 45.0 | $[\frac{1}{2}y_{2x}]^{2}y_{3x}[y_{3x}]^{2}$ | 38.0 | 42 | 39.0 |
| Mo | i sa saira | al saund | | ue, es h | phi si a si | 108 | 121 |
| Pđ | м. | | | | | 148 | 150 |
| λkX | 1.433 | 1.433 | 1.389 | 1.337 | 1,293 | 1.360 | 1.360 |

Comparison of $(\frac{\mu}{\rho})$ for 1.360 kX units

with values given by other observers.

* Values obtained by interpolation from other wavelengths.

The values by Andrews⁽³⁾ were measured for the characteristic emission lines of various elements selected by means of a vacuum spectrometer, while those by Allen,⁽⁴⁾ Martin and Lang⁽⁴⁾ are for homogeneous characteristic X-rays reflected from calcite. Allen's results at 2.24 kX units were measured for filtered general radiation, the effective wavelength being estimated from the absorption by Aluminium.

The other investigators, Grosskurth, Biermann, and Laubert⁽¹⁷⁾ used X-rays monochromatised by a filter method due to Kustner⁽¹⁸⁾, where the characteristic radiation of an element was excited by irradiation with short wavelength X-rays and the Ka,a, doublet separated by means of selective filters. We see therefore that X-ray beams containing $K \alpha_i$ and $K \alpha_i$ wavelengths were employed by all the observers mentioned, while the present work with Copper and Cobalt radiation was carried out with very pure beams of only the $K \alpha_i$ wavelengths.

The results may be directly compared, however, because the two wavelengths are so near that there is practically no difference between the mass absorption coefficients at the K a and K wavelengths. It is seen from the tables that the present results are in good agreement with those of the other investigators.

Reasonable agreement is also shown at 2.285 and 1.360 kX units, for which the present values were obtained by graphical analysis of absorption curves taken with a beam of Chromium $K\alpha$, radiation contaminated by other wavelengths, and were therefore not so accurate as direct measurements with pure wavelengths.

It must be noted that most of the values used for comparison were not measured with pure monochromatic X-rays of wavelength 2.285 kX, but were due to Allen, who employed filtered general radiation with an estimated effective wavelength of 2.24 kX.

The only measured values at these wavelengths for Beryllium are due to Andrews, who employed evaporated foils and flakes for his measurements. It is seen that his values are consistently higher than the present results. as shown separately in table (4.5).

| | A | ndrews | Present Work | Table |
|------------|--------------|---------------------------------|---------------------------------|---------------------------------|
| Specimen | Flakes | Foils | Lamp specimen | |
| Impurities | 0.4% Fe | Cu Fe Si W | Mg Fe Mn Si | varues |
| Wavelength | (<u>#</u>) | $\left(\frac{\mu}{\rho}\right)$ | $\left(\frac{\mu}{\rho}\right)$ | $\left(\frac{\mu}{\rho}\right)$ |
| 1.537 | 4.87 | 6.0 | 2.10 | 1.35 |
| 1.753 | 5.04 | | 2.37 | 2.42 |
| 2.285 | 10.01 | 16.3 | 4.47 | 4.74 |

TABLE 4.5

Since the Beryllium used by Andrews contained nearly 1% of higher atomic number impurities, he states that the values obtained are possibly as much as 100% higher than they would be for pure Beryllium. The present results are in very good agreement with table values, and as far as is known are the only other measurements carried out with Beryllium at these wavelengths.

Andrew's results indicate the marked effect impurities have on the absorption coefficient.

4.2.

THE ATOMIC ABSORPTION COEFFICIENTS (Ma)

(as given by the present results)

The absorption coefficients for single atoms

may be obtained from the mass absorption values by multiplying by the absolute mass of the atoms $^{A}/_{N}$ where A is the atomic weight of the element concerned, and N the Avogadro number. The values calculated from the present results are shown in tables (4.6) and (4.7). The figures show how the values depend on the atomic number and wavelength.

| TABLE | 4 | .6 |
|-------|---|----|
| | | |

| | (z) | | A 23 | 1.5374 kX | | | 1.7853 kX | | |
|----|--------|------------|-------------------------------|--------------------|--------------------------|--------------------------------------|-----------|----------|-------------------------------------|
| | Number | Weight (A) | $\frac{\Lambda}{N} \times 10$ | $\frac{\mu}{\rho}$ | $\mu_{a} \times 10^{23}$ | $\log_{10} (\mu_{a} \times 10^{23})$ | H P | Max 1023 | $\log_{10}(\mu_{a} \times 10^{23})$ |
| Be | 4 | 9.02 | 1.497 | 2.10 | 3.14 | 0.487 | 2.37 | 3.55 | 0,550 |
| C | 6 | 12.01 | 1,993 | 4.46 | 8.89 | 0.949 | 7.21 | 14.4 | 1.158 |
| Al | 13 | 26.97 | 4.478 | 49.6 | 838 | 2.347 | 74.9 | 336 | 2.526 |
| Fe | 26 | 55.85 | 9.272 | 309 | 2860 | 3,457 | 55.1 | 512 | 2.709 |
| Ni | 28 | 58,69 | 9.744 | 53.3 | 520 | 2.716 | 74.0 | 721 | 2.858 |
| Cu | 29 | 63.57 | 10.55 | 50.8 | 536 | 2.729 | 75.8 | 800 | 2.903 |
| Zn | 30 | 65,38 | 10.85 | 60.4 | 656 | 2.817 | 84.4 | 916 | 2.962 |
| Mo | 42 | 95.95 | 15.93 | 158 | 2520 | 3.401 | 216 | 3440 | 3.536 |
| Pd | 46 | 106.7 | 17.72 | 192 | 3390 | 3.531 | 289 | 5120 | 3.709 |

| FABLE | 4.7 |
|-------|-----|
| | |

| | (Z) | | | | 2.2850 kX | | | 1.360 kX | | |
|----|------------------|----------------------|------------------------------|--------|--------------------------|--------------------------------------|--------------------|--------------------------|-------------------------------------|--|
| | Atomic Number | Atomic Weight (A) | $\frac{A}{N} \times 10^{-1}$ | H P | $\mu_{a} \times 10^{23}$ | $\log_{10} (\mu_{e} \times 10^{23})$ | $\frac{\mu}{\rho}$ | $\mu_{a} \times 10^{23}$ | $\log_{10}(\mu_{a} \times 10^{23})$ | |
| Be | 4 | 9.02 | 1.497 | 4.51 | 6.75 | 0.829 | 1.27 | 1.90 | 0.279 | |
| C | 6 | 12.01 | 1.993 | 13.4 | 26.7 | 1.427 | 2.99 | 5.96 | 0.775 | |
| Al | 13 | 26.97 | 4.473 | 165 | 738 | 2.868 | 31.7 | 142 | 2.152 | |
| Fe | 26 | 55,85 | 9.272 | 106 | 983 | 2.993 | 258 | 2392 | 3.379 | |
| N1 | 28 | 58,69 | 9.744 | 146 | 1423 | 3.153 | 290 | 2826 | 3.451 | |
| Cu | 29 | 63.57 | 10,55 | 152 | 1603 | 3.205 | 38.5 | 406 | 2.609 | |
| Zn | 30 | 65.38 | 10.85 | 159 | 1725 | 3.237 | 39.0 | 423 | 2.627 | |
| Mo | 42 | 95.95 | 15.93 | 455 | 7245 | 3.860 | 121 | 1928 | 3.285 | |
| Pd | 46 | 1.06.7 | 17.72 | 572 | 10140 | 4.006 | 150 | 2659 | 3.405 | |

VARIATION OF THE ATOMIC ABSORPTION COEFFICIENT WITH ATOMIC NUMBER.

Since the atomic absorption coefficient changes abruptly at the K critical absorption wavelength, we can divide the results at any one wavelength λ into two groups, namely,

(1) Those of elements for which $\lambda_{\kappa} > \lambda$

(2) Those of elements for which $\lambda_{\kappa} < \lambda$ where λ_{κ} is the critical absorption wavelength of the element concerned.

The graphs, figs (4.1) and (4.2) show $\log_{10} (\mu_{\star} \times 10^{23})$ against $\log_{10} (Z)$ for the elements in the two groups at the four different wavelengths used in this investigation, and in each case straight lines are obtained, which indicate that the atomic absorption coefficients are proportional to powers of the atomic numbers. We may therefore write

$$\mu_{a} = C_{\chi} Z^{II}$$

where C_{λ} is a constant, which has different values at different wavelengths and for the two groups $\lambda_{\kappa} > \lambda$ and $\lambda_{\kappa} < \lambda$. The values obtained for C_{λ} and the exponent <u>n</u> from the graphs are shown in table (4.8).

TABLE 4.8.

| Wavelength | $\lambda_{\kappa} > \lambda$ | λ , λ | $\lambda_{\kappa} < \lambda$ | | |
|------------|------------------------------|-----------------------|------------------------------|------|--|
| kX units | $C_{\lambda} \times 10^{25}$ | n | $C_{\lambda} \times 10^{25}$ | n | |
| 1,360 | 0.607 | 3,92 | 0.0569 | 4.00 | |
| 1.5374 | 0.962 | 3,88 | 0.0795 | 3.99 | |
| 1,7853 | 1.479 | 3,88 | 0.1140 | 4.00 | |
| 2.285 | 3.090 | 3.86 | 0.2291 | 4.00 | |
| | Mean = | 3.9 | Mean = | 4.0 | |

4.3 (a)





112

We may note here, that at the shorter wavelengths, and for the light element Beryllium, the curves depart from straight lines because the scattering of the X-rays is becoming appreciable.

(b) Comparison with the results of other investigators.

This

variation of the atomic absorption coefficient with atomic number has not been very extensively investigated. Early work with short wavelengths gave a value 4 for the exponent of Z, while recent measurements at long wavelengths indicate a much higher value of about 4.5. The few results available are given in table (4.9) together with the wavelength range over which the measurements were carried out.

| | $\lambda_{\kappa} > \lambda$ | e Li Alexa | $\lambda_{\kappa} < \lambda$ | 5 at |
|----------------------------|------------------------------|---------------|------------------------------|------|
| Author | Wavelength range | n | Wavelength range | n |
| Bragg & Pierce | 0.491-0.615 | 4.0 | 0.491-0.615 | 4.0 |
| Walter ⁽²³⁾ | 0.1-1.0 | 3.94 | 0.1-1.0 | 4,3 |
| Grosskurth ⁽¹⁵⁾ | 0.1279-2.2863 | 3.7 | 0,1863-2,2863 | 4.04 |
| Present work | 1.332 2.286 | 3.9 | 1,332-2,286 | 4.0 |
| Woernle ⁽²⁰⁾ | 3.5 | 3.9 | * * * * * * * * * | |
| Woernle ⁽²⁰⁾ | 9.5 | 3.7 | 9.5 | 4.6 |
| (اع) Dershem & Schein | | | 44.5 | 4.4 |
| Kurtz ⁽²²⁾ | | | 44.5 | 4.4 |

TABLE 4.9

The present results are in good agreement, and there seems to be evidence that for metals in the group $(\lambda_{\kappa} > \lambda)$ the exponent <u>n</u> decreases as the wavelength increases, while for $(\lambda_{\kappa} < \lambda)$, the exponent <u>n</u> increases with the wavelength.

4.4. VARIATION OF THE ATOMIC ABSORPTION COEFFICIENTS

WITH WAVELENGTH.

(a) Again it is convenient to consider the results in two groups,

(1)
$$\lambda_{\kappa} > \Lambda$$
 (2) $\lambda_{\kappa} < \lambda$
and the graphs, figs, (4.3) and (4.4) show $\log_{10} (\mu_{o} X)$

1023)

against \log_{10} (λ X 10⁸) for different elements in each group respectively.

The straight lines obtained indicate that for all the elements considered here, with the exception of Beryllium, the atomic absorption coefficient is proportional to a power of the wavelength. For the light element Beryllium, however, we get a departure from the straight line at the shorter wavelengths because the scattering of the X-rays has become an important factor. We may write this time

$$u_{\alpha} = C_{\mathbf{Z}} \lambda^{\mathbf{m}}$$

where C, is a constant which has different values for different elements and for the two wavelength ranges $(\lambda_{\kappa} > \lambda)$ and $(\lambda_{\kappa} < \lambda)$. The values obtained for C_{g} and m from the graphs are given in the table (4.10) together with the mean value of λ_{λ} and λ_{λ} for the elements over the wavelength range covered by the measurements.

We see at once that there is a distinct change in the value of the exponent m with atomic number at these wavelengths. With the exception of Beryllium, the elements give a value for the exponent m which decreases as the atomic number increases.





(b) Comparison with the results of other investigators.

| | 2 | $\lambda < \lambda_{\kappa}$ | | , , , , , , , , , , , , , , , , , , , | $\lambda > \lambda_{\kappa}$ | J i con |
|-------|-----------------------------------|--------------------------------------|------|--|-----------------------------------|---------------------------|
| , * a | Mean $\lambda_{\lambda_{\kappa}}$ | C ₂ X 10 ²³ | m | Mean $\lambda_{\lambda_{L}}$ | C _z X 10 ²³ | m |
| 4 | | 0.7228 | 2.79 | ante de la composition de la c | | |
| 6 | .0420 | 2,530 | 2.97 | an a chair. | a hai shiye a s | a dai ta |
| 13 | .2304 | 60.64 | 2.89 | | | e di selis Si si selis |
| 26 | .8363 | 941.9 | 2.73 | 0.138 | 107.2 | 2.77 |
| 28 | | Strive of t | | 0.154 | 151.0 | 2.73 |
| 29 | | | | 0.161 | 163.7 | 2.73 |
| 30 | | n forma personal na contenario en | | 0.177 | 194.1 | 2.67 |
| 42 | | | | 0.424 | 822.1 | 2.60 |
| 46 | | | | 0.531 | 1188 | 2,50 |

TABLE 4.10

This change of the exponent <u>m</u> with atomic number was first observed by Allen⁽⁵⁾ in 1926. He also shows a change in <u>m</u> with wavelength, quoting values between 2.6 and 2.7 near the edges of the K absorption bands of the elements, but becoming greater than 2.9 for shorter wavelengths.

This suggests that for measurements in the range $\lambda \leq \lambda_{\kappa}$ the exponent of λ is a function of $(\lambda/\lambda_{\kappa})$ having a value 3 when $(\lambda/\lambda_{\kappa}) = 0$, and then decreasing to about 2.6 as λ/λ_{κ} increases to unity.

It then follows that for measurements carried out on a number of elements at the same wavelength, we have <u>m</u> decreasing with increasing atomic number, because λ/λ_{κ} increases.

Similarly for measurements in the region $\lambda \leq \lambda_{\perp}$ we can postulate that <u>m</u> decreases from 3 to about 2.5 as λ_{λ} increases from zero to unity.

The present results as well as the large amount of work that has been carried out by many investigators , on the best exponent for λ for different elements and over different wavelength ranges verify these statements.

The two graphs, figs (4.5) and (4.6) show values of <u>m</u> at different values of λ/λ_{κ} and λ/λ_{ι} respectively, as given by the present results and deduced from other sources.



4.5 EMPIRICAL ABSORPTION FORMULAE DEDUCED FROM THE RESULTS.

A number of investigators have put forward empirical expressions to represent the absorption coefficients in terms of the atomic number Z of the absorber, and wavelength λ of the absorbed radiation.

At short wavelengths expressions of the form

 $\mu_a = A Z^4 \lambda^3 + B \qquad (4.1)$

were given, where the first term represents the fluorescent coefficient (τ_{α}) and the second term the scattering coefficient (δ_{α}). The value of the constant A changes at the critical absorption wavelengths, while the constant B has a different value for each element.

At longer wavelengths the scattering coefficient is small compared with the fluorescent coefficient, so that expressions of the form

were given, where the exponents <u>n</u> and <u>m</u> have values lying between 3.5 and 4.5, and 3 and 2.5 respectively, depending on the wavelength range covered by the various formulae.

For example,

Walter⁽¹⁵⁾ (0.1 - 1.0 kX)

 $(\lambda < \lambda_{\kappa}) \qquad \mu_{a} = 1.60 \times 10^{-2} z^{3.94} \lambda^{3} / N$ $(\lambda > \lambda_{\kappa}) \qquad \mu_{a} = 5.29 \times 10^{-4} z^{4.30} \lambda^{3} / N$

where N is Avogadro's number (6.0228 x 10²³)

Grosskurth (0.1 -2.3 kX)

 $\mu_{a} = 2.836 \times 10^{-2} z^{3.70} \lambda^{2.737} | N$ $\mu_{a} = 12.66 \times 10^{-4} z^{4.04} \lambda^{2.737} | N$

The present results cover a part of this longer wavelength region, so that similar empirical relations may be deduced from them.

We see that for a constant wavelength λ the expression (4.2) reduces to

 $\mu_a = c_{\lambda} z^n$ where $c_{\lambda} = A \lambda^m$ and gives the variation of the atomic absorption coefficient with atomic number. Similarly, for a constant Z, that is, for one particular element the expression becomes

 $\mu_a = c_z \lambda^m$ where $c_z = A z^n$ and gives the variation of the atomic absorption coefficient with the wavelength.

Equations of this type were obtained in Sections (4.3) and (4.4), where for the wavelength range covered the mean values obtained for the exponents m and n were

> (1) $(\lambda < \lambda_{\kappa})$ m = 2.9 ; n = 3.9 (2) $(\lambda > \lambda_{\kappa})$ m = 2.7 ; n = 4.0

A number of values of C_{λ} and C_{Z} were also given from which the constant A is readily calculated, as shown in the table (4.11).

We find that it has a different value for $\lambda < \lambda_k$ and $\lambda > \lambda_k$.

TABLE 4.11

| STREET. | | 7 | $1 < \lambda_{\kappa}$ | | $\lambda > \lambda_{\kappa}$ | | | | | |
|--|----------|-------------|---------------------------|----------------------|------------------------------|------------------------|-----------------------------------|----------------------|--|--|
| | λ (kx) | m | $C_{\chi} \times 10^{25}$ | A x 10 ²¹ | λ (kx) | m | $C_{\lambda} \times 10^{25}$ | A x 10 ²⁷ | | |
| and the second | 1.360 | 2.9 | 0.607 | 2.452 | 1.360 | 2.7 | 0.0569 | 2.640 | | |
| | 1.537 | 1.1.1 | 0.962 | 2.800 | 1,537 | l GBC - J | 0.0795 | 2,533 | | |
| 1.14 | 1.785 | 1.194 | 1.479 | 2.804 | 1,785 | 6 6 14 6 6 14 | 0.1140 | 2.450 | | |
| | 2.285 | 1078 111 | 3.090 | 2 .8 63 | 2,285 | | 0.2291 | 2.541 | | |
| 214 ¹⁰ 1017 | Z | n | $C_z \times 10^{23}$ | | 7. | n | C ₂ x 10 ²³ | | | |
| - Andreas | 4 | 3.9 | 0.7228 | 3,243 | 26 | 4.0 | 107.2 | 2,360 | | |
| and the second | 6 | | 2,530 | 2:334 | 28 | i, ji | 151.0 | 2,456 | | |
| | 13 | | 60.64 | 2.747 | 29 | | 163.7 | 2.315 | | |
| | 26 | | 941.9 | 2,858 | 30 | çi e | 194.1 | 2.397 | | |
| | e têst î | . 7% | | 2011년 - | 42 | 문학 | 822.1 | 2.643 | | |
| | part Fr | | 1 - 1 | a di si | 46 | $d_{1} \in \mathbb{C}$ | 1188 | 2.653 | | |
| | | Mean | A = 2.80 | x 10 ⁻²⁶ | | Mean . | A = 2.50 x | 10 ⁻²⁷ | | |

Our empirical absorption formulae then become;

(1)
$$(\lambda < \lambda_{k})$$

 $\mu_{a} = 2.80 \times 10^{-20} z^{3.9} \lambda^{2.9}$
(2) $(\lambda > \lambda_{k})$
 $\mu_{a} = 2.50 \times 10^{-27} z^{4.0} \lambda^{2.7}$

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1. 19

4.5. The K absorption jump ratios, as given by the present
(b) empirical formula.

A good check on the accuracy of an empirical absorption formula is to compare the K absorption jump ratios calculated from it, with the usually accepted values. In the present case, the absorption jump R_k is given by

$$R_{k} = \frac{2.80 \times 10^{-27} Z^{4.0} \lambda_{k}^{2.7}}{2.50 \times 10^{-27} Z^{4.0} \lambda_{k}^{2.7}} = \frac{11.20 \lambda_{k}^{0.7}}{Z^{0.1}}$$

Now according to the Bohr theory, the energy of binding of an electron in the K orbit is given by

$$N = \frac{2\pi^2 m e^{\xi^4}}{h^2} Z^2 = Rch Z$$

where $R = \frac{2\pi^2 m e^{5}}{c h^3}$ and is called the Rydberg constant.

Hence if V_k is the critical absorption frequency we can write approximately $V_k = R c Z^2$, so that $\lambda_k = \frac{1}{R Z^2}$ and our equation for the absorption jump ratio becomes

$$R_k = \frac{11.20}{R^{\circ 2} Z^{\circ 5}} = \frac{43.75}{Z^{1/2}}$$

Values of R_k calculated from the present formula are given in table (4.12) and are compared with the experimental values of several observers in table (4.13). It is seen that they are in excellent agreement with the observed values, especially when the large differences between the values of different investigators are taken into account.

The agreement is not nearly so good for other absorption formulae, as seen from the dotted curves (fig.4.7), which were drawn from the empirical formulae of Walter and Grosskurth - as typical examples.



| | | A Barriston Last march 1 | | |
|----|----|--------------------------|----------------------|--------------------------------------|
| | Z | Z | 1 / Z ¹ 2 | $R_{\kappa} = \frac{43.75}{2^{1/2}}$ |
| 0 | 8 | 2.828 | 0.3536 | 15.47 |
| Al | 13 | 3,606 | 0.2773 | 12.13 |
| S | 16 | 4.000 | 0.2500 | 10.94 |
| Cl | 17 | 4.123 | 0.2425 | 10.61 |
| A | 18 | 4,243 | 0,2356 | 10.31 |
| Fe | 26 | 5,099 | 0.1961 | 8,580 |
| N1 | 28 | 5.292 | 0.1889 | 8,265 |
| Cu | 29 | 5.385 | 0.1857 | 8,123 |
| Zn | 30 | 5.477 | 0.1826 | 7,990 |
| Mø | 42 | 6.481 | 0.1543 | 6.750 |
| Pd | 46 | 6.782 | 0.1473 | 6.453 |
| Ag | 47 | 6.856 | 0.1459 | 6.384 |
| Sn | 50 | 7.071 | 0.1414 | 6.185 |
| I | 53 | 7.280 | 0.1374 | 6.010 |
| Ba | 56 | 7.483 | 0.1336 | 5.845 |
| Ta | 73 | 8.544 | 0.1170 | 5.120 |
| W | 74 | 8.602 | 0.1163 | 5.090 |
| Pt | 78 | 8.832 | 0.1133 | 4.957 |
| Au | 79 | 8.888 | 0.1125 | 4.921 |
| Pb | 88 | 9.055 | 0.1104 | 4.830 |
| U | 92 | 9.592 | 0.1043 | 4.562 |

Calculated K absorption jump ratios

TABLE 4.13

Comparison of the calculated K absorption jump ratios with some observed values

| (25) (24) | 0 | A1 | S | C1. | A | Fe | Ni | Cu | Zn | Mø | Pd | Ag | Sn | I | Ba | Ta | W | Pt | Au | Pb | υ |
|-------------------------------------|------|------|----------|--------|-------|------------------------|-----|-------|------------|------|--------|------|-------|------|-----|-----|--|---------------------|--|-----------------|--|
| Jonsson | | 12.6 | | | | | 8.3 | 8.2 | | | | 1.15 | | | | | | 3 (₁ .) | | | |
| Weernle | | | 11.0 | 10.4 | 10.0 | | | | 1997. A.S. | | ar sti | | | | | | • | | | 5.649 FL | |
| Walter | | | | | i a r | 9.4 | 9.1 | 9.0 | 8.9 | | 7.6 | 7.6 | | | | | 2 | | | | |
| Allen | | | | т. | 2,53 | 9.2 | 8.2 | 8.5 | 7.5 | | | 7.3 | 8.9 | 5.5 | 5.2 | 4.2 | 1 | 6.0 | 1.1.1 | | 2.9 |
| Martin | | | | | | 8.8 | 8.8 | 8.3 | 7.7 | | 6.6 | 6.7 | | 1.7 | | | 4 | | | ্রান্ সংজ্ঞা | |
| & Lang/ Richtmyer & Warburton | | | | | | | | and a | | 7.5 | | 7.8 | 6.6 | | | | 5.65 | | 5.65 | 5.40 | |
| Gray | | | | | , v | 8.0 | 7.7 | 7.6 | 7.4 | D | 5.7 | 5.5 | 1-0-1 | | | 1.5 | S all | | Provide la la | | 1952.9 |
| Holweck | 14 | 13 | | | 110.4 | | | | | | | | | | 1 | | | | | | |
| Rudfleisch | 17.6 | 13.0 | | | | 8.5 | 8.1 | 7.9 | 7.7 | | 5.9 | 5.8 | | | | QJ. | 4.4 | | 4.2 | 4.1 | |
| Stoner & Martin | | | | | | | | | | | 6.8 | 6.7 | | | | | | | | | |
| Richtmyer | | | Ar Sarah | | | 1.17 | | | | 8.7 | 1.47 8 | 7.3 | 22.10 | 1.18 | | 1.1 | 1. | 1 | 2.46° X 1.47 1722 (1.47) 1722 (1.47) | 2.1.21 | and the second s |
| Spencer | | | | | 9.96 | 2011 - 10 2011 - 10 | | | | St e | | | | | | | | | | | |
| Mean Values | 15.8 | 12.9 | 11.0 | 10.4 | 9.98 | 8.8 | 8.2 | 8.2 | 7.85 | 811 | 6.5 | 6.84 | 7.75 | 5.5 | 5.2 | 4.2 | 5:00 | 6.0 | 4 93 | A 45 | 2.9 |
| Calculated values | 15.5 | 12.1 | 10.9 | 10.6 | 10.3 | 8.6 | 8.3 | 8.1 | 8.0 | 6.8 | 6.5 | 6.4 | 6.2 | 6.0 | 5.8 | 5.1 | 5.0 | 5.0 | 4.9 | 4.8 | 4.6 |

4.6. Approximate mass scattering coefficients deduced from the empirical absorption formula and known values of total mass absorption coefficients.

In table (4.14) some mass absorption coefficients calculated by means of the empirical formula were compared (25)(26) with the usually accepted values. There is good agreement except for the light elements at the shorter wavelengths, where the accepted values are consistently higher than those calculated, due to the increasing contribution of the X-rays scattered by the elements to their absorption coefficients.

| λ | a | 0,5 | 0 kX | 1.00 | ¢Χ | 1.54 | kX | 2,50 | kX |
|----|---------------------|-------|----------|--------|------------|-----------|------------|------------|------|
| | Z Cale Obs Hp Mp | | Calc Obs | | Calc Mp | Obs Mp | Calc Mp | Obs P/p | |
| C | 6 | 0.204 | 0.355 | 1.52 | 1.60 | 5.34 | 5.50 | 21.7 | 20.0 |
| 0 | 8 | 0.470 | 0.520 | 3.51 | 3.15 | 12.2 | 11.2 | 50.0 | 45.0 |
| Ne | 10 | 0.896 | 0.930 | 6.64 | 6.50 | 23.2 | 24.0 | 95.5 | 100 |
| Al | 13 | 1.85 | 1.90 | 13.8 | 14.1 | 48.1 | 49.0 | 197 | 196 |
| A | 18 | 4.45 | 5.00 | 33.2 | 35.0 | 116 | 116 | 473 | 475 |
| Ca | 20 | 6.68 | 6.70 | 49.9 | 49.0 | 173 | 172 | 711 | 620 |
| Fe | 26 | 13.6 | 14.5 | 99.9 | 101 | 347 | 328 | | |
| Cu | 29 | 18.0 | 18.6 | 134 | 130 | 51.4 | 50.9 | | |
| Mo | 42 | 50.4 | 50.2 | 49.0 | 52.0 | 158 | 164 | | |
| Ag | 47 | 10.0 | 10.5 | 68.4 | 73.0 | 220 | 217 | , M. | |
| Sn | 50 | 12.3 | 13.0 | 79.5 | 87.0 | 253 | 247 | | |
| W | 74 | 37.9 | 39.0 | 246 | 260 | 1.03 | 5 e - 1 | | |
| Au | 79 | 45.9 | 49.0 | ta tha | | Sec. 1 | | | |
| Pb | 82 | 50.7 | 53.0 | 1.200 | | -31 D | 1. A. A. | | |

TABLE 4.14.

| TABLE | 4 | 01 | 5 |
|-------|---|----|---|
| | | - | |

Mass scattering coefficients obtained by means of the empérical absorption formulae

| | | H/2 obs | γ _ρ cale | 6/p | | Ϋ́ρ calc | 6/p | ₽⁄ _/ p | ₩ calc | % | Mp obs | ۳/p calc | 6/p |
|----|----|------------|------------------------|-------|--------|-------------|-------|-------------------|-----------|-------|-----------|-------------|-------|
| Li | 3 | 0.125 | 0.000 | 0.125 | 0.151 | 0.002 | 0.149 | 0.198 | 0.024 | 0.174 | 0.430 | 0.177 | 0.253 |
| Be | 4 | 0.131 | 0.000 | 0.130 | 0.160) | 0.004 | 0.156 | 0.210 | 0.056 | 0.154 | 0.550 | 0.418 | 0.132 |
| в | 5 | 0.138 | 0.001 | 0.137 | 0.165 | 0.008 | 0.157 | 0.250 | 0.111 | 0.139 | 0.930 | 0.831 | 0.100 |
| C | 6 | 0.148 | 0.002 | 0.140 | 0.175 | 0.014 | 0.161 | 0.355 | 0.204 | 0.151 | 1.60 | 1.53 | 0.07 |
| Na | 11 | 0.150 | 0.011 | 0.140 | 0.225 | 0.080 | 0.145 | 1.25 | 1.13 | 0.12 | 8.80 | 8,47 | 0.33 |
| A1 | 13 | 0.156 | 0.017 | 0.139 | 0.270 | 0.130 | 0.140 | 2.00 | 1.85 | 0.15 | 14.12 | 13.80 | 0.32 |
| Fe | 26 | 0.275 | 0.126 | 0.149 | 1.20 | 0.938 | 0.260 | 14.5 | 1.3.6 | 0.9 | 101 | 99.9 | 1.1 |
| Ag | 47 | 1.05 | 0.655 | 0.395 | 5.40 | 4.88 | 0.52 | 10.5 | 10.0 | 0.5 | | 1 | |
| Sn | 50 | 1.17 | 0.758 | 0.412 | 6.10 | 5.66 | 0.44 | 13.0 | 12.3 | 0.7 | | | |
| Pb | 82 | 3.50 | 2.99 | 0.510 | | | | | 1 | | | | |
| λ | kX | | 0.10 | | | 0.20 | | | 0,50 | 1 | | 1.00 | |

Since the empirical formula was deduced for a wavelength region where the scattering was very small compared with the fluorescent absorption of the X-rays , it gives in effect values of the fluorescent mass absorption coefficients at these wavelengths. It follows that , if the formula is reasonably accurate at shorter wavelengths, we can obtain approximate values for the mass scattering coefficients by subtracting the calculated fluorescent coefficients from the usually accepted total mass absorption values.

This has been done for a few elements at four different wavelengths, as shown in table (4.15), and the values are compared in table (4.16) with the measured values of several investigators.

We may note that, since the scattering coefficients are small, slight variations in the values of the total mass absorption coefficients of different observers will result in large errors in the values of the scattering coefficients. On the whole, however, the results are in reasonable agreement with the given values, especially when we take into consideration that scattering coefficients are rather difficult to measure experimentally and that disagreements of as much as 30% are not uncommon between the results of different observers.

The graphs, figs, (4.7) and (4.8) show how the scattering coefficients vary with atomic number and wavelength. We see that for light elements, over a wavelength range (0.1 to 0.5 kX) the mass scattering coefficient is almost constant and independent of atomic number and wavelength as is required by the classical scattering theory of J.J.Thomson.



TABLE 4.16

| · 11.4810- | λ (kX) | L1 | Be | B | C | Na | Al | Fe | Ag | Sn | Au | Pb |
|----------------------|--------|--|-------|--------|------|---------|-------|------|------|-------|------|-------|
| Allen (27) | .098 | $\int_{-\infty}^{\infty} \left[\left(\frac{1}{2} - \frac{1}{2} \right) \right]^{1/2} dt$ | P.e. | 1 | .139 | i ji da | .143 | 162 | | 1.934 | | |
| Present work | .100 | .125 | .130 | .137 | .140 | .140 | .139 | .149 | .395 | .412 | | .51 |
| Allen | .130 | | . P. | | .151 | | .149 | .189 | | 2,582 | | 3.12 |
| Allen | .200 | | | | .167 | | .155 | .254 | | 4.04 | | - |
| Present work | .200 | .149 | .156 | .157 | .161 | .145 | .140 | .262 | .52 | 0.44 | | 1.1.1 |
| Allen | .417 | | | | .173 | | .1.61 | .282 | | 4.44 | × | |
| Mertz ⁽⁵⁾ | .430 | .165 | | .162 | .182 | .1.91 | | | | | | |
| Coade (28) | .48 | - | | | .183 | | .1.6 | .25 | | 0.40 | .93 | |
| Present work | .50 | .174 | .154 | .139 | .151 | .120 | .150 | .40 | .50 | 0.70 | 3.1 | 2.3 |
| Mertz | .54 | .157 | | .169 | .194 | .248 | 1 | | | | с | |
| Coade | .55 | | | | .186 | | .200 | .320 | .52 | 0.56 | 1.32 | |
| Coade | .09 | | e | | .330 | | .420 | | | | | |
| Present workl | 00 | .253 | .132 | .100 5 | | .33 | .32 | 1.1 | | | | |

MASS SCATTERING COEFFICIENTS $(\frac{\delta}{P})$ FOR DIFFERENT ELEMENTS AT VARIOUS WAVELENGTHS

For shorter wavelengths the scattering rapidly becomes less than this theory predicts, while for heavier elements and longer wavelengths, it rapidly increases above the classical value . This is explained by the quantum theory which considers the radiation scattered by a material to consist of two parts :-

- (1) The incoherent or modified scatter for which the wavelength of the scattered radiation is changed.
- (2) The coherent or modified scatter where the wavelength remains unchanged.

The mass scattering coefficient is then due to these two types of scattering processes, the relative importance of each part depending on the atomic number of the scatterer, and the wavelength of the radiation scattered.

For light elements irradiated with X-rays in the region 0.1 to 0.5 kX units, the two parts contribute more or less equally to the scattering coefficient, while at shorter wavelengths the scattering coefficient is almost entirely due to the incoherent part which diminishes slowly with the wavelength.

At longer wavelengths and for higher atomic numbers, the coherent part is the more important, and we have excess scattering which increases rapidly above the classical value, being proportional to, approximately $Z^2 \lambda$, according to the present results.
CONCLUSION.

We end this section with a brief summary of the main conclusions arrived at during the course of the investigation.

The process of the absorption of X-rays over a wide range of wavelength and atomic number is not simple, and the fluorescent mass absorption coefficient cannot be represented accurately over the whole range by a simple formula of the type

$$\gamma = \alpha \lambda^n z^n$$

where <u>n</u> and <u>m</u> are constants and α is a parameter whose value changes at the critical absorption edges.

Instead, the present results, as well as those of other workers, indicate that the exponents \underline{n} and \underline{m} vary with the wavelength and atomic number over an extended range of values of these quantities.

A survey of the work carried out on the exponent <u>m</u> of the atomic number shows that the value increases with wavelength, but there is not enough data available to arrive at a definite law concerning the variation.

In the case of the variation of the fluorescent mass absorption coefficient with wavelength, the results indicate that the exponent <u>n</u> of the wavelength decreases with $\lambda_{\lambda_{\kappa}}$ on the short wavelength side of the K absorption edge, and with $\lambda_{\lambda_{\kappa}}$ on the long wavelength side of the edge.

Over a small range of λ and Z however, <u>m</u> and <u>n</u> can be considered as constant and empirical formulae of the form $\gamma = \alpha \lambda^n z^m$ give reasonably good values of the fluorescent mass absorption coefficients.

The formulae deduced in the present case are

(1)
$$\lambda < \lambda_{\kappa}$$
 $\mu_{\alpha} = 2.80 \times 10^{-26} Z^{3.9} \lambda^{2.9}$
(2) $\lambda > \lambda_{\kappa}$ $\mu_{\alpha} = 2.50 \times 10^{-27} Z^{4.0} \lambda^{2.7}$

where μ_{α} is the atomic mass absorption coefficient.

When the K absorption jump ratio is calculated from these empirical absorption formulae we obtain

$$R_{\rm H} = 43.75/~{\rm Z}^{\prime\prime}$$

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which indicates that the ratio is inversely proportional to the square root of the atomic number. The formula gives values in excellent agreement with those observed by various investigators.

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Lastly, values of the mass scattering coefficients estimated by means of the empirical absorption formulae, are in reasonable agreement with the few directly measured values available, and obey the general laws of scattering. In the excess scatter region, the results indicate that the coefficient is approximately proportional to Z^2 .

References.

19 - 19 - 44

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|---|
| (1) E.A.Owen, Proc Roy Soc Lond A 86 (1912) p 426 |
| (2) W.H.Bragg, Phil Mag 29 (1915) p 407 |
| Barkla and White, Phil Mag 34 (1917) p 270 |
| E.A.Owen, Proc Roy Soc Lond A 94 (1918) p 339 |
| (3) Hewlett, Phys Rev 20. (1922) p688 |
| (4) Statz, Zeits F Physik 11 (1922) p 304. |
| (5) P Mertz, Phys Rev 28 (1926) p 891 |
| (6) S.J.M.Allen Phys Rev 28 (1926) p 907 |
| (7) H.H.Johann, Zeitschr F Physik 69 (1931) p 185 |
| (8) Du Mond and Kirkpatrick, Rev Sci Inst 1. (1930) p 88 |
| (9) H.Friedmann, Electronics 18 (1945) p 132 |
| (10) E.H.Cooke-Yarborough, C.D.Florida and C.N.Davey 26. Journ Sci Inst. (1949) p 124 |
| (11) J.Rotblat, E.A.Sayle and D.G.A.Thomas Journ Sci Inst 25. (1948) p 33 |
| (12) W Cochran Act Cryst 3 (1950) p 268 |
| (13) Andrews, C.L. Phys Rev 54 (1938) p 994 |
| (14) Martin, L.H. & K.C.Lang Proc Roy Soc A. 137 (1932) p 1 |
| (15) Grosskurth, K Ann der Physik 20 (1934) p 197 |
| (16) Biermann, H.H. Ann der Physik 26 (1936) p 740 |
| (17) Laubert, S. Ann der Physik. 40 (1941) p 553 |
| (18) Kustner, H. Zeits der Physik 70 (1931) p 324 |
| (19) Bragg, W.H. & S.E.Peirce. Phil Mag 28. (1914) p 625 |
| (20) Wornle, B. Ann der Physik, 5. (1930) p 475 |
| (21) Dershem, E. & E. Schein Phys Rev 37. (1931) p 1238 |
| (22) Kurtz H. Ann der Physik 85 (1928) p 529 |
| (23) Walter, B. Fortschritte a d Geb der Rontgen |
| (24) Colvert, W.W. Phys Rev 36 (1930) p1619. |
| (25) Landolt - Bornstein Zahlenwerte und Funktionen Band 1 |
| (26 Compton A.H.& S.K.Allison. X-rays in Theory and Experimen |
| (27) S.J.M.Allen Phys Rev 45 (1934) p 122. |
| (28) Coade, E.N. Phys Rev 36 (1930) p 1109. |