THE EFFECT OF THE MAGNETIC FIELD ON THE ABSORPTION OF X-RAYS.

BY JOSEPH A. BECKER.

SYNOPSIS.

Effect of a magnetic field on the absorption of x-rays, if it can be measured, would have an important bearing on the theory of atomic structure. Since the effect is very small, a differential method was adopted and by eliminating various spurious effects the apparatus was made sensitive enough to detect a change of 1 part in 10,000. Observations were made with a peak voltage of 80 kv. across the Coolidge tube (mean wave-length about 0.3 Å.) and with a magnetic field H of about 18,000 gauss. For H perpendicular to the rays, *aluminum, carbon, copper, iron, nickel, platinum, zinc, and silver* showed changes in absorption coefficients of $+ 8 \pm 6$, $- 5.6 \pm 2$, $+ 0.8 \pm 0.4$, $- 10 \pm 2$, $+ 1.6 \pm 0.5$, $+ 1.7 \pm 0.4$, $- 1.2 \pm 0.4$ and $+ 1.6 \pm 0.8$ parts in 10,000 respectively, while with H parallel to the rays the corresponding changes were $+ 2.7 \pm 1$, $+ 3 \pm 1$, $+ 1.4 \pm 1$, $- 0.5 \pm 2$, $+ 0.7 \pm 2$, $+ 1.1 \pm 1$ and $+ 1.3 \pm 1 \times 10^{-4}$, silver not being tried. These results are in accord with the hypothesis that the magnetic properties are largely determined by the outer shell or valency electrons, since at the wave-lengths used by far the greater part of the absorption is due to the inner electrons. Wood was also tested with softer rays having a mean wave-length of about 1.2 Å., and showed a change of $+ 80 \pm 20 \times 10^{-4}$ as compared with 3×10^{-4} for carbon for wave-length 0.3 Å. Following the suggestion of this result it is proposed to do further work with light elements and softer x-rays.

Differential Method of Measuring Small Changes of Intensity of an X-ray Beam.—The apparatus, which includes two similar ionization chambers connected so that the ionization currents nearly neutralize each other, is described in detail together with the precautions necessary to eliminate various sources of error and to attain the sensitivity mentioned above.

Bumstead Electroscope.—*A simple type* is described. Care should be taken to eliminate convection currents within the instrument.

THE following investigation was undertaken because of the conviction that the structure of the atom cannot be satisfactorily explained without taking into account magnetic forces. It was hoped that an applied magnetic field would orient the ultimate magnetic particle and that this shifting would result in a measurable change in the absorption of x-rays. A study of this effect would throw a new light on the nature of the ultimate magnetic particle and on its function in the atom.

This search is not new. In 1914 and 1916 Dr. Forman[1] sought for this effect in iron. In his second paper he reports an increase in absorption of five to seven parts in a thousand when iron is magnetized in a direction parallel to the x-ray beam. Soon thereafter A. H. Compton[2]

[1] PHYS. REV., *3*, 306–313, 1914 and *7*, 119–124, 1916.

[2] J. Wash. Acad. Sci. *8*, 1, 1918 and PHYS. REV., *14*, 20–43 and 247–259, 1919.

developed his theory of scattering and later stated "that the effect observed by Forman is of the order of magnitude to be expected if the electrons are rings of electricity which are oriented by the magnetic field."[1] This led him to look for a change in γ-ray absorption in magnetized and unmagnetized iron. He reports negative results of .023 ± .018 and .004 ± .019.[3]

Since 1916 our knowledge of x-ray production and absorption, as well as the technique of control and measurement, has advanced sufficiently to warrant a repetition of Forman's work as well as an extension to other materials than iron.

Apparatus.

The method used is essentially a differential one and is necessarily so because the changes sought are small.

The general arrangement of apparatus was much the same as that used by Forman. A radiation-type, tungsten-target Coolidge tube, T,[2] is practically completely enclosed in a lead box L, Fig. 1, and sends two

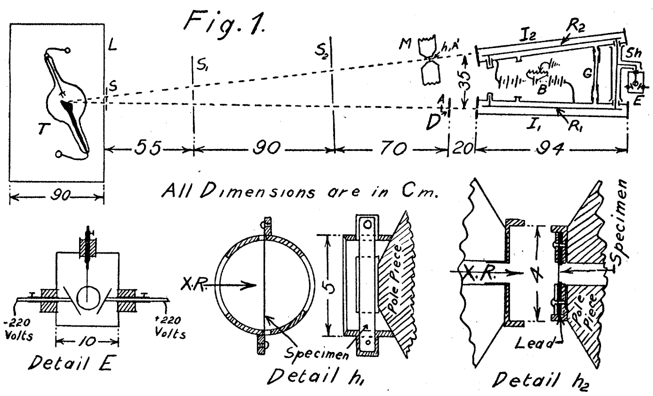


Fig. 1.

beams of x-rays through three pairs of preliminary lead slits, through the absorbers A and A', and into two identical ionization chambers I_1 and I_2. The rods R_1 and R_2 are connected together and to the leaf of a Bumstead electroscope E.[3] This system can be earthed by means of a mercury-break key, and is shielded from electrostatic disturbances by a tin shield Sh. The casings of the ionization chambers, as well as the movable plates of the electroscope, are connected to the terminals of a 420-volt battery of dry cells, B, whose middle point is earthed. G is a

[1] Phys. Rev., 17, 38–41, 1921.
[2] Very kindly placed at the disposal of Prof. Richtmyer by Dr. Coolidge.
[3] Am. J. of Sci., 32, 405–406, 1911 and Phil. Mag., 22, 910, 1911.

glass tube connecting the two chambers. M is a powerful electromagnet of Swiss type. The diameter of the face of the pole-pieces was 2 cm. in the first part of the investigation and 4 cm. in the second part. h is a holder to be described in detail later. D is a rectangular opening of lead, the upper edge of which is attached to a slow motion screw.

The procedure is as follows: one specimen is placed between the pole-pieces, while an exactly similar one is placed in front of D. The size of the slit at D is varied until practically no net charge accumulates on the rods R_1R_2 and the leaf shows either a small rate of drift or none at all. The magnet is energized. If the absorption of the specimen in the field is increased, the ionization in I_2 will decrease, and the leaf will show a change in the rate of drift ($\Delta\delta$) where δ is the rate of drift in divisions per minute. By subsequently determining how much the height of the slit at D must be increased to produce the same $\Delta\delta$ we can compute $\Delta I/I$, the proportional change in the intensity of the transmitted beam. Then by means of a formula to be developed later we can compute $\Delta\mu/\mu$, the proportional change in the absorption coefficient due to the field H.

Since the effect is small it is necessary to be able to keep the two ionization currents balanced to within 1 or 2 parts in 10,000. Consequently every effort was made to reduce the errors to a minimum. The larger part of the time was taken up in determining and eliminating spurious changes in δ. The following list gives the chief factors to be guarded against.

Sources of Error.

(*a*) Electrostatic effects.
(*b*) Unsteadiness of leaf of electroscope.
(*c*) High-resistance leaks.
(*d*) Stray x-radiation.
(*e*) Slight changes in the position of the focal spot.
(*f*) Changes of current through the tube.
(*g*) Peculiarities of the ionization chambers.
(*h*) Effect of the magnetic field on the tube or ionization chambers.
(*i*) Movement of the specimen caused by H or by the slight shifting of the pole-pieces.

To show how these errors were eliminated it is necessary to give a detailed description of the apparatus.

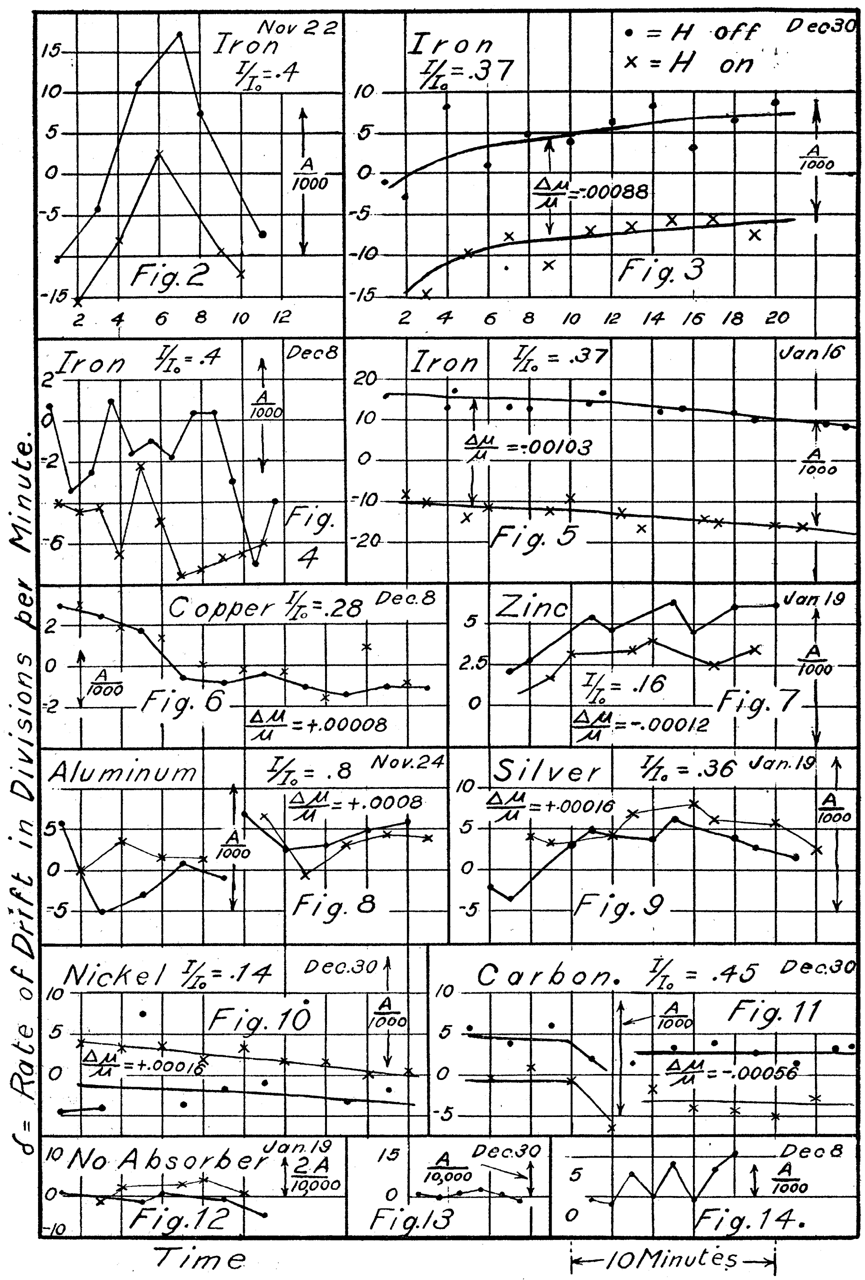
The Electroscope.

Fig. 1 shows a detail drawing of the electroscope. It can be constructed by an amateur mechanic in a short time. The brass box was made detachable, but the joints were sealed with wax to make them air tight. The plates and the leaf are adjustable. Sulphur insulation was found convenient and satisfactory. The position of a definite point on the gold-leaf was observed through a low-power microscope with a 50-division scale in the ocular. These 50 divisions correspond to approximately 2 mm. At first considerable difficulty was encountered in keeping the grounded leaf at rest. The trouble was finally ascribed to heat convection currents, and was eliminated by completely enclosing the instrument with a cardboard housing. The working sensitivity of the leaf was about 80 div. per volt on the leaf. This sensitivity could easily have been increased four or five fold by either lowering the leaf, moving both plates closer, or by increasing the voltage on the plates.[1] At the high sensitivities it becomes somewhat more difficult to keep the position of the leaf steady. Unsymmetrical changes of voltage on the plates were about one fifth as effective in deflecting the leaf as the same voltage on the leaf, *e.g.*, if the ground is shifted one volt the resultant deflection is the same as if the leaf had been charged to .2 volt. This fact necessitated keeping the relative voltages on the plates constant to within 10 millivolts. When not too old, the dry cells proved satisfactory so long as their temperature was kept constant.

The drift in the leaf due to change of plate voltage, high resistance leaks, and electrostatic disturbances was seldom more than 5 divisions in half an hour. Neither was the rate of drift increased by running the x-ray tube with the openings at h and D closed by small lead plates. This shows that the first four sources of error mentioned above were effectively eliminated. To accomplish this it was found essential completely to inclose the tube with lead and put up the preliminary screens.

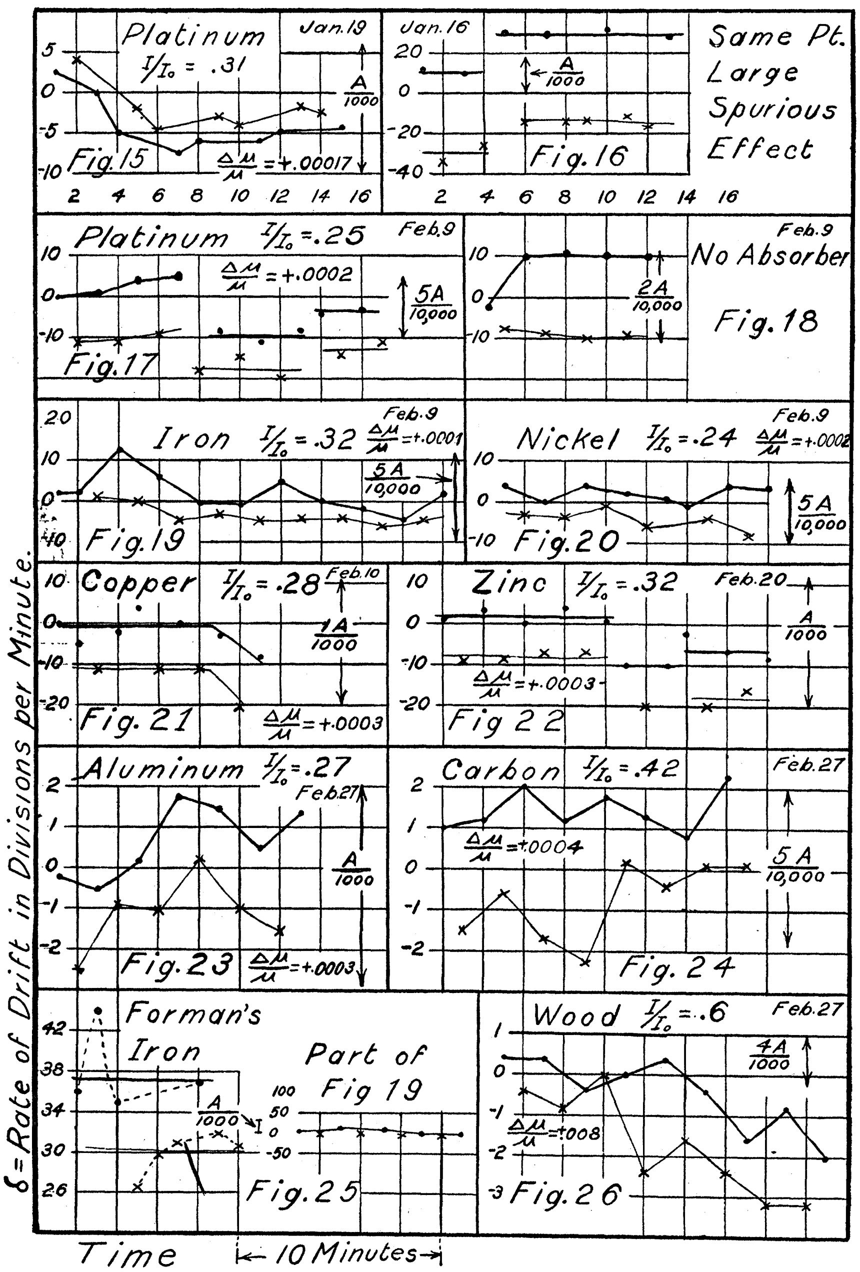
Sources of error e, f, and g were found by repeatedly observing that δ would change radically whenever the current through the tube changed. At this time the high tension for the tube was furnished by a G. E. x-ray transformer while the filament was supplied from a step-down transformer. Even though the primary of both transformers was supplied from a rotary converter (D.C. to A.C.) whose voltage could be kept constant to within 2 per cent., yet the current through the tube would vary as much as 50 per cent. Ideally this should not have disturbed a balance since both beams should be affected equally. Practically it did and the only satisfactory way of keeping the current steady was to light the filament by means of a 12-volt storage battery in the high-tension circuit. The filament current was varied by means of a slide-resistance operated by an insulated handle. Even with this arrangement the contacts in the filament circuit were gone over periodically to insure steady currents.

[1] Dadourian, Phys. Rev., 14, 238, 1919, obtained a working sensitivity of 5,000 divisions per volt.



In all Figs. the values of δ for H off are represented by $\cdot$; for H on, by an x. H = approx. 18,000 gauss.

In Figs. 2 to 16, H was perpendicular to the x-rays; the voltage was 80 kv. peak; a $+\Delta\delta$ means a decrease in I, or an increase in μ.



In Figs. 17 to 24, H was parallel to X; the voltage was 80 kv. peak; a $+\Delta\delta$ means an increase in I or a decrease in μ.

In Fig. 26, H was parallel to X; the voltage was 27 kv. peak; a $+\Delta\delta$ means a decrease in μ.

A pin-hole picture of the focal spot showed that it consisted of a ring 7/16 inch in diameter with two irregular small areas inside. Consequently if the first slit S is narrow and the focal spot for any reason shifts, even though the shift is so slight as to be imperceptible, a slightly different area becomes effective in illuminating the slit at D and thus the balance is destroyed. The preliminary slits were therefore made 3/4 inch wide while the final slits at D and h were only 1/8 to 1/4 inch wide. In this way every point of the final slit received radiation from every point of the focal spot even though the focal spot did shift slightly. Incidentally, widening the preliminary slits also increased the available energy. The improvement brought about by this change shows up clearly by contrasting the steadiness in Figs. 2 and 14 for narrow slits with Figs. 3 and 13 for the widened slits.

The ionization chambers were made of brass tubing and were fitted with square ends. They were mounted on sulphur supports. The rods were supported and insulated by sulphur plugs containing the usual earthed guard rings. The chambers were filled with methyl bromide. Unfortunately this gas in the presence of moisture reacts with zinc and copper thus making it necessary to refill the chambers every three or four weeks. When doing so, care was taken to fill both chambers to the same pressure, otherwise a change in the tube current of .1 milliamp might unbalance the ionization in the chambers by several parts in 1,000. Later the two chambers were connected by a glass tube.

During the course of the investigation it was noticed that the balance was particularly sensitive to slight shifts in the rear end of the ionization chambers. A further study revealed the fact that an appreciable percentage of the ionization was caused by photoelectrons emitted by the rear end of the chamber. Materials of low atomic weight were found to cause a smaller increase in the ionization than those of high atomic weight. The arrangement decided upon as least troublesome was an aluminum plate coated on the inside with wax.

Spurious Effects Due to the Magnetic Field H.

Forman found that the stray field of his electromagnet deflected the electron stream in his tube. He finally remedied the difficulty by means of compensating coils and iron screens. The magnet in this present investigation was placed at a considerable distance from the tube. Its stray field near the tube was less than the earth's field and when possible was opposed to it. The final test as to whether the stray magnetic field affects either the tube or the ionization is to make blank runs either with no absorbers or with absorbers in front of the magnet. Several such runs were made and in no case was any effect greater than 2 parts in 10,000 obtained. (See Fig. 18).

Several times large apparent changes in absorption were noted when the specimen was between the pole-pieces, but in all such cases it could be shown that either the field distorted the specimen or the shifting of the pole-pieces displaced the specimen. This was particularly true in the case of iron and nickel, and with thin specimens. Fig. 16 shows a spurious change of about $2\frac{1}{2}$ parts in 1,000. Due to the high absorption coefficient for platinum the specimen was only 1 or 2 mils thick. Small forces might easily distort the thin specimen. When this same specimen was pasted on a thin uniform strip of wood and another run taken, as shown in Fig. 15, ΔI is only a few parts in 10,000. Practically the same result was obtained when the specimen was tightly clamped in the holder.

The Specimen Holders.

Two holders h_1 and h_2 were designed and are shown in detail in Fig. 1. h_1, which was used when H was perpendicular to the rays, consists of a brass collar with bevelled edges which match the pole-pieces. Two screws fasten the specimen to two ledges at opposite ends of a diameter. Perpendicular to this diameter are openings to allow the beam to pass. This holder may not be as reliable as the accuracy of the remainder of the outfit warrants. Consequently a new one has been designed which, it is hoped, will give more reliable results.

Holder h_2 was carefully designed and constructed. It was used when H was parallel to the rays. The specimen is firmly held in front of the lead opening by means of screws passing through the brass cover. The pole-pieces are firmly screwed up against the holder.

The Final Slit at D.

The opening at D was usually 3/16 inch wide and about 1/2 inch high. A balance was obtained by changing the height by means of the micrometer screw. One turn corresponds to 1/100 inch and there are 100 divisions on the drum. Thus with a slit 1/2 inch high, 5 drum divisions ($5D$) correspond to a change in area of 1 part in 1,000, *i.e.*, $A/1,000$. By noting δ for a series of positions of the drum, $\Delta\delta$ for $10D$, or else $\Delta\delta$ for $A/1,000$ can be computed. The uniformity of intensity of the x-ray beam over the whole opening was shown by the fact that this ratio was independent of the height of the opening.

In all measurements of large rates of drift, say greater than 60 divisions per minute, it was found necessary, in order to get consistent results, to apply a correction to the observed δ. Table I. gives the values of the corrections to be added to the absolute value of the observed δ. These corrections were obtained by noting δ for a number of openings differing by equal small steps and plotting δ against the opening. Instead of a straight line, a curve was obtained which deviated more and more from the straight line as δ increased. The deviations gave the corrections to be added. This lag is probably due to air friction and is a function of the dimensions and shape of the leaf and the air pressure. It is analogous to the lag in a quadrant electrometer.

TABLE I.

Observed δ	50	100	150	200	250	300	400
Correction	.5	2.5	9	19	37	60	90

SENSITIVITY OF APPARATUS.

To show how sensitive the apparatus is, one need only obtain a balance, and then interpose a very thin sheet of paper. After a few seconds' lag the leaf begins to drift and continues to do so until a few seconds after the paper is removed. A few degrees change in temperature in the slit D can be detected; the slight "give" in the floors caused by a person walking past the supports for the slit D produces an observable effect; air currents also cause disturbances. Under these circumstances it seems almost hopeless to try to measure an effect less than one part in 1,000 with an accuracy better than 10 per cent. However, if the temperature and current could be maintained constant and if mechanical disturbances were minimized, the apparatus could detect changes as small as 2 or 3 parts in 100,000.

COURSE OF A COMPLETE RUN.

The following illustrates the course of a complete run.

Voltage across tube: 80 kv. peak.

Sensitivity of leaf: 44.2 div./volt.

1. Steady test: x-rays shut off by lead plates. Position of leaf every 15 seconds:

25.2	25.2	25.0	25.0	24.9	24.9	24.9	24.8	24.8	24.8	24.7	24.7
24.7	24.5	24.4	24.2	24.2	24.2	24.2	24.2	24.1	24.0	24.0	24.0
24.0	24.0	23.9	23.8	23.9	23.9	23.9	23.8	23.7	23.6	23.6	23.7
23.7	23.7	23.7	23.6								

2. Sensitivity determination with no absorber in.

Size of opening = 3,900 drum divisions or 3,900 D,

Drum scale 20 up $\delta = -40 \times 60/11.4 = -210$ Corrected $\delta = -230$,
Drum scale 25 up $\delta = -23.3 \times 60/30 = -46.6$ Corrected $\delta = -47$,
Drum scale 30 up $\delta = 40 \times 60/18.9 = 127$ Corrected $\delta = +131$,

$$\Delta\delta/10D = 180 \times 2 = 360 \text{ for } 2.2 \text{ milliamps} = 82 \text{ per milliamp},$$
$$\Delta\delta \text{ for } A/1000 = \Delta\delta/10D \times 3.9/10 = 140.$$

3. Steady test with x-rays entering chambers. Readings of leaf every 15 seconds:

19.0	19.5	18.5	19.5	20.0	20.7	19.5	18.5	19.7	21.0	22.0	21.0
21.0	21.5	21.8	22.5	24.0	23.8	24.0	25.0	25.3	25.0	24.0	24.0

4. Sensitivity with iron absorber in. Opening: $3800D$.

Drum 40 up $\delta = -40 \times 60/15 = -160$ Corrected $\delta = -170$,
Drum 60 up $\delta = -20 \times 60/13 = -92$ Corrected $\delta = -94$,
Drum 80 up $\delta = -12$ Corrected $\delta = -12$,

$$\Delta\delta/10D = (76 + 82)/2 \times 2 = 39.5 \text{ for } 1.3 \text{ milliamps} = 30.4 \text{ per milliamp},$$

$$I/I_0 = \frac{\Delta\delta/10D \text{ for Fe absorber}}{\Delta\delta/10D \text{ for no absorber}} = 30.4/82 = .37,$$
$$\Delta\delta \text{ for } A/1000 = (39.5/10) \times 3.8 = 15.$$

5. Effect of magnetic field on absorption of iron. $H = 18{,}000$ gauss. H is put on for one minute every other minute starting with the second. The position of the leaf is read every 15 seconds.

		H Off——		—|——		—*H* On		
				Switch closed				Switch opened
33.0	32.8	33.0	34.0	33.0	31.5	29.2	25.5	24.5
	26.0	28.0	29.7	30.8	29.0	26.0	25.0	24.8
	26.2	30.0	31.2	34.0	32.5	30.0	28.3	28.5
	28.8	29.5	30.5	30.5	29.5	29.0	27.5	30.0
	31.0	34.0	35.8	36.5	34.0	32.0	30.0	29.0
	31.0	33.0	35.5	38.0				

A positive $\Delta\delta$ means an increase in absorption, or a decrease in I.

From this data the average δ for each minute was computed and plotted in the latter half of Fig. 3.

This figure shows a change of δ due to H equal to -13 div. Since $\Delta\delta$ for $A/1000 = 15$;

$$\frac{\Delta I}{I} = -\frac{-13}{15 \times 1000} = +\frac{8.7}{10{,}000}.$$

From a formula developed below

$$\frac{\Delta\mu}{\mu} = -\frac{1}{\log_e(I_0/I)} \cdot \frac{\Delta I}{I} = -1.005\frac{+8.7}{10{,}000} = \frac{-8.8}{10{,}000}.$$

Consequently a field of 18,000 gauss decreases the absorption coefficient of iron by 8.8 parts in 10,000.

DEVELOPMENT OF FORMULÆ.

As is well known,

$$I = I_0 e^{-\mu t}. \tag{1}$$

If μ can be made to change in a given specimen, then

$$\frac{dI}{d\mu} = -tI_0 e^{-\mu t} = \frac{\Delta I}{\Delta\mu} = -tI \tag{2}$$

or

$$\frac{\Delta I}{I} = -t\Delta\mu.$$

From (1)

$$t = \frac{\log(I_0/I)}{\mu}; \quad \therefore \frac{\Delta I}{I} = -\frac{\Delta\mu}{\mu} \times \log\left(\frac{I_0}{I}\right)$$

or

$$\frac{\Delta\mu}{\mu} = -\frac{1}{\log(I_0/I)} \cdot \frac{\Delta I}{I}. \tag{3}$$

Given: I_0, μ, and $\Delta\mu$ for a certain material. What is the best thickness to use so that ΔI shall be a maximum?

From (2)

$$\Delta I = -I_0 t e^{-\mu t} \Delta\mu$$

For a maximum

$$\frac{d(\Delta I)}{dt} = 0$$

or

$$-I_0\Delta\mu(e^{-\mu t} - \mu t e^{-\mu t}) = 0$$

Since I_0, $\Delta\mu$, and $e^{-\mu t}$ are not zero,

$$1 - \mu t = 0 \quad \text{or} \quad \mu t = 1$$

or

$$\log_e I_0/I = 1, \quad I_0/I = 2.73; \quad I/I_0 = .368.$$

That is ΔI, which determines $\Delta\delta$, will be greatest if t is so chosen that $I/I_0 = .368$.

RESULTS.

Figs. 2–16 show the results obtained with H perpendicular to the path of the x-rays; Figs. 17–26, the results for H parallel to the x-rays. For all but the last two figures the peak voltage across the tube was about 80 kilovolts, which corresponds to a minimum wave-length of .15 Å. The maximum energy was probably in the neighborhood of .3 Å. Each figure contains the date on which the data were obtained, the values of

$\Delta I/I$, $\Delta\mu/\mu$, and $\Delta\delta$ for $A/1000$. It is important to take this last-named factor into account when comparing the curves.

A comparison of the steadiness of this apparatus with that attained by Forman is given in Fig. 25 which shows Forman's results for iron with 81 kv. (R.M.S.) across the tube, and the present result for iron under similar conditions, both plotted to practically the same scale.

Figure 26 shows one of two preliminary runs with a peak voltage of 27 kv. across the tube. A previous run on wood at the higher voltage had revealed a $\Delta\mu/\mu$ of 4 or 5 parts in 10,000. At the lower voltage the sensitivity, consistency, and reliability are considerably less but still $\Delta\mu/\mu$ is clearly about 8 parts in 1,000 or about 16 times as large as before. This would indicate that larger changes may reasonably be looked for at longer wave-lengths with low atomic weight elements. This clue, it is hoped, can be followed up in the next few months.

The results show that while the magnetic field does change the absorption of x-rays in various materials the effects for wave-lengths near .3 Å. are small. At this wave-length the largest effect is shown by iron for which $\Delta\mu/\mu$ is about 1 part in 1,000 when H is perpendicular[1] to X. For H parallel to X, Fig. 19 shows that the change is much smaller,[1] which may be partly due to the large demagnetizing field for such a thin sheet of iron. Of the other materials examined carbon and aluminum show the largest change. Nickel, platinum, copper, zinc and silver show changes smaller than 3 parts in 10,000 for either direction of H. At a mean wave-length in the neighborhood of 1.2 Å., wood shows a change in absorption of about 8 parts in 1,000 for H parallel to x-rays.

The following list sums up the values of $\Delta\mu/\mu$[2] together with an estimated probable error. The conditions under which each value was obtained can be found in the figures or in the legend for the figures. The estimate of the probable error is based on the oscillations of δ, the value of $\Delta I/I$ due to H for no absorber, and on the author's experience and judgment of the likelihood of small spurious effects.

All results are expressed in number of parts change in 10,000, a plus sign meaning an increase in μ.

For H perpendicular to X rays:

Iron -10 ± 2,	Nickel $+1.6 \pm 0.5$,	Platinum $+1.7 \pm 0.4$,
Copper $+0.8 \pm 0.4$	Zinc -1.2 ± 0.4,	Silver $+1.6 \pm 0.8$,
Carbon -5.6 ± 2,	Aluminum $+8 \pm 6$.	

[1] Opposite to Forman's results.

[2] Corrected for a small effect observed with no absorber, which was never greater than 2 parts in 10,000.

For H parallel to X rays:

Iron $- 0.5 \pm 2$,	Nickel $+ 0.7 \pm 2$,	Platinum $+ 1.1 \pm 1$,
Copper $+ 1.4 \pm 1$,	Zinc $+ 1.3 \pm 1$,	Carbon $+ 3 \pm 1$,
Aluminum $+ 2.7 \pm 1$,	Wood (longer wave-lengths) $+ 80 \pm 20$.	

Discussion of Results.

These results are in accord with the hypothesis that magnetic properties are largely conditioned by the outer atomic shell or valency electrons. If the magnetic fields inside the atom are actually as large as is supposed, we cannot hope to penetrate deeply into the atom with external fields. Consequently we should hardly expect to produce any changes in the inner shells. Now it is generally believed that the K absorption and emission are associated with the innermost shell while the L and M radiations are due to the next two shells of electrons respectively. Professor Richtmyer[1] has shown that very probably for wave-lengths less than the K_a limit, by far the larger part of the absorption is used up in exciting the K fluorescent radiation, a small percentage of the energy absorbed, for example, let us say 5 per cent., excites the L fluorescence, and presumably even a much smaller percentage, let us say .5 per cent., goes to excite the M fluorescence. On the above hypothesis we should expect to be unable to affect the K and L absorption of all substances having three or more shells of electrons. To be specific, let us consider aluminum which on Langmuir's theory contains a K shell of 2 electrons, an L shell of 8 electrons, and an outer shell of 3 electrons. If the external magnetic field produces no change in the K and L absorption but as much as a 10 per cent. change in the absorption due to the outer shell, the change in the total absorption would amount to only $.10 \times .005$ or 5 parts in 10,000. On the other hand, carbon which contains only 2 shells would on the same suppositions show a change in the total absorption equal to $.10 \times .05$ or 5 parts in 1,000. We should also expect a larger change in the total absorption if the wave-length were longer than the K_a limit. Both of these expectations are supported by the fact that at a given wave-length carbon and aluminum show larger changes than the heavier elements (excepting possibly iron and nickel), and that wood shows larger changes at long than at short wave-lengths.

On Compton's theory of scattering we might look for an appreciable change in that part of the absorbed energy which is scattered. In the low atomic weight elements a large percentage—as much as 50 per cent. —of the absorbed energy goes into scattered radiation. This investigation shows that the change in the scattered radiation cannot exceed about 1 part in 1,000.

[1] Phys. Rev., 18, 13–30, 1921.

The most hopeful region to work in seems to lie near the absorption limit of the outermost shell. The most promising materials are the ones in the first two groups of the periodic table. While the experimental difficulties in working in the neighborhood of 100 Å. are great, the author believes that it will be well worth the effort and hopes to have the opportunity of continuing the search in that direction.

In conclusion the author wishes to express his appreciation and gratitude for the ever helpful and never failing encouragement, inspiration and assistance received from Professor Richtmyer.

Cornell University,
Ithaca, New York,
March, 1922.