TABLE III. *Properties of* $FeNi_3$ *for which a change by long range order would be expected and the results as known.*

PROPERTY	CHANGE	INDICATION
Resistivity, ρ	Increase on cold working or quenching	Ordering
$d\rho/dT$	-8.5% on annealing the cold worked alloy	No ordering
Magnetic saturation at room temperature	No change	No ordering
Magnetic permeability	High on quenching	None
Specific heat	15 cal./g peak	Ordering or magnetic transformation
X-ray diffraction	No superstructure lines	No long range ordering

ments, and obtains 191 cal./g-atom = 3.3 cal./g. Since from theoretical considerations one would expect the energy to vary directly with the Curie temperature and the saturation magnetization, for $FeNi_3$ the energy should be

$$Q=3.3(870/630)(12200/6100)=9.1 \text{ cal./g.}$$

This shows that if long range order is present we should expect the specific heat measurements to give a value of about 28 cal./g, while if it is absent a value of about 9 cal./g. Thus there is reason to expect that Kaya's value for the aged specimen, 15 cal./g, can be explained by the magnetic transformation. In this case the value for the quenched material is too small and is difficult to understand.

Kaya points out also that if there is ordering in $FeNi_3$, the high permeability is associated not with its presence but with its prevention, since the high permeability is produced by rapid cooling or quenching, and is reduced on aging. This effect would be in the direction opposite to the usual result; e.g. in Ni_3Mn the permeability at room temperature is increased by ordering.

The properties of $FeNi_3$ which one would expect to be affected by long range order and the results as known to date are summarized in Table III.

Thus the negative result of the x-ray work indicates definitely that no long range order exists in $FeNi_3$, and this nonexistence is supported by a considerable amount of less direct evidence.

The author wishes to acknowledge his indebtedness to Drs. R. M. Bozorth, F. C. Nix, and W. Shockley for many valuable discussions.

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A Determination of e/m from the Refraction of X-Rays in a Diamond Prism

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Measurements of the index of refraction of the copper K_β line by a diamond prism have been made with an estimated accuracy of one part in 10,000. These measurements together with the quantum theory of dispersion and the ruled grating wave-length of the copper K_β line afford a method of evaluating e/m with an accuracy comparable to that of previous determinations by other methods. The value of e/m is given by the equation

$$\frac{e}{m}=\delta\left[\frac{\lambda^2\rho F}{2\pi W}\sum_1^s N_s\{1+A\}\right]^{-1},$$

where δ, λ, ρ, R, N_s and W have their usual meaning and A is the factor which takes into account the electronic binding. For carbon and a $\lambda^{2.75}$ law of absorption, the value of the $\sum_1^s=6.0163\pm0.0006$. Using $\delta=9224.4\times10^{-9}$, $W=12.0148$, $\rho=3.5154$, $F=96513.1$, $\lambda=1.39220\text{A}$, one obtains $e/m=(1.7601\pm0.0003)\times10^7$ e.m.u. This bound electron value is higher than most previous spectroscopic determinations but is in excellent agreement with the free electron results of Dunnington.

In the present unsettled state of the values of the fundamental constants it is of importance to determine the value of each constant by as many different methods as possible. In practically all of the experimental methods of evaluating constants, in reality one only measures the value of the constant of proportionality in an equation connecting a group of constants. Precise measurements of the refractive index for x-rays in material of low atomic number together with the dispersion theory afford such a method of evaluating either the wave-length of the x-rays used or the constant e/m. The other constants entering the equation are either known or can be measured with a higher degree of precision than the value of e/m. In the present work on the dispersion of x-rays, the generally accepted ruled grating wave-length has been assumed and the value of e/m determined with a precision which appears comparable with the best previous evaluations.

The general dispersion theory equation[1] can be solved for e/m in the following convenient form:

$$\frac{e}{m}=\delta\left[\frac{\lambda^2\rho F}{2\pi w}\sum_1^s N_s\{1+A\}\right]^{-1}, \qquad (1)$$

where e/m is the ratio of the electronic charge to its mass, $\delta=1-\mu$, μ is the index of refraction, λ is the wave-length of the incident x-rays of frequency ν, ρ is the density and w the molecular weight of the refracting substance, F is the Faraday constant, N_s is the number of electrons per molecule of frequency ν_s, A is a factor which takes into account the electronic binding and the absorption of the x-rays in the refracting substance. The small corrective factor A contains the only difference between the various theories of dispersion. The value of A depends on the variation of the absorption coefficient of x-rays with wave-length. For all practical purposes a law of the form λ^n is sufficiently accurate.[2] In the present case $n=2.75$. It is very difficult to evaluate A unless n is an integer or half-integer. Therefore in the following calculations the value of e/m has been calculated on the assumptions of a λ^3 and $\lambda^{2.5}$ law and the $\lambda^{2.75}$ law value interpolated. If $X_s=\nu/\nu_s$ the formulae for A are:

$$A=(1/X_s^2)\ln(X_s^2-1) \qquad (2)$$

on the assumption of a λ^3 law and

$$A=\frac{3}{2X_s^{\frac{3}{2}}}\left(\frac{\pi}{2}-\mathrm{ctn}^{-1}X_s^{\frac{1}{2}}-\tfrac{1}{2}\ln\frac{X_s^{\frac{1}{2}}+1}{|X_s^{\frac{1}{2}}-1|}\right) \qquad (3)$$

on the assumption of a $\lambda^{2.5}$ law.

EXPERIMENTAL PROCEDURE

An uncertainty in the evaluation of e/m from (1) is the factor A. This can be made small by using x-rays of short wave-length and a refracting prism of as low atomic number as possible. It is also apparent that in order for δ to be measured precisely it is necessary for the density ρ to be large and the substance homogeneous. An inspection of the available materials shows that diamond is by far the best. In a right-angle prism as used in the present work (Fig. 1) only one large optically flat surface is essential, for a negligibly small deviation is produced by the other surface. The other surface forming the prism edge should be flat but not necessarily as flat as the large surface and furthermore it need not be very large.

With the aid of a grant from the Rumford Committee of the American Academy of Arts and Sciences, the writer has been particularly fortunate in securing a perfect diamond slab 9×9×3 mm from Schenck and van Haelen of New York. Mr. van Haelen ground the large surface and one edge forming a 90 degree prism. He then attempted to polish these surfaces optically flat by the usual diamond polishing technique. This method was abandoned after repeated trials failed to give a surface flat within one wave-length of yellow light. The diamond grinding machine used for grinding ruling engine points for optical gratings in the laboratory at the Johns Hopkins University was then rebuilt. The polishing surface of the steel grinding disk was carefully finished and all bearings and the diamond holder adjusted as accurately as possible. After the necessary diamond polishing technique had been acquired, the surfaces were finally made flat within 0.1 wave-length of mercury light. The edge appeared perfectly sharp under a microscope of 300 magnification.

The methods used for determining the index of refraction are shown in Figs. 1 and 2. In Fig. 1 the x-ray beam struck the first face of the prism at a glancing angle slightly larger than the critical angle of total reflection. The continuous x-ray spectrum of longer wave-length was reflected from this face of the prism and was used to determine the angle between the direction of the incident x-ray beam and the surface of the prism. This reflected beam was recorded on the photographic plate at D, at the same time that the refracted beam was recorded at C. The prism was then moved out of the path of the x-ray beam and the direct beam recorded

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[1] J. A. Wheeler and J. A. Bearden, Phys. Rev. **46**, 775 (1934).

[2] E. J. Williams, Proc. Roy. Soc. **A143**, 358 (1934).

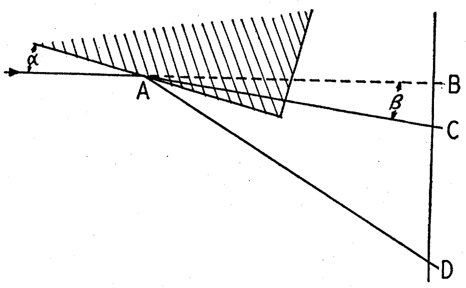

FIG. 1. The refracted x-ray line strikes the diamond prism at an angle α greater than the angle for total reflection and is refracted to C. Longer wave-lengths of the continuous spectrum are totally reflected to D. B is recorded by removing prism from path of x-ray beam.

at B. The angles α and β needed for determining μ can be obtained from the separations of the lines on the photographic plate, and the distance from the point of incidence on the prism face A to the photographic plate. The index of refraction μ may be calculated from the equation

$$\mu = 1 - \delta = \frac{\cos \alpha}{\cos (\alpha - \beta)}.$$

In Fig. 2 the direction of the x-ray beam is reversed and one needs to measure a small angular rotation of the prism in order to determine the angle α. The angle α was obtained by rotating the prism through a known angle ϕ which gave total reflection of the x-ray beam to A'. Then

$$\phi - \tan^{-1} (A'C/R) = \alpha.$$

In determining the angle β Fig. 2 the distance from the prism edge to the second plate (about 200 cm) was carefully measured and then the distance from the edge to the refracting point was subtracted from this distance. This and the distance B to C on the plate give the angle β. The advantage of this method is that, because the refracted beam is slightly convergent, very sharp lines result and all wave-lengths suffer maximum deviation simultaneously.

In previous photographic refraction measurements only the very edge of the prism could be used because of high absorption, which necessitated measurements to the edges of the photographic lines. The low absorption of the diamond made it possible to have the entire x-ray beam pass through the prism as much as 3.0 mm from the edge along the large surface. Photographs were made with the beam striking or emerging from the large surface at various positions up to the edge of the prism. The close agreement of these results indicated the perfectness of the prism.

The slits, axis of rotation of the prism, and plate holders were precisely aligned by the method used in the measurement of x-ray wave-lengths by ruled gratings.[3] The edge of the prism was placed on the axis of rotation and parallel to it with the aid of a Michelson interferometer.

The collimating gold slits were about 0.003 mm wide and 40 cm apart. The position of the prism in the x-ray beam was easily determined by the use of an ionization chamber. Normalized[3] Eastman x-ray plates were used for recording the positions of the various x-ray lines.

The average temperature of the underground room in which the experiment was performed was held within 0.05°C at all times. The variation in temperature due to the heating and cooling cycle (about 5 minutes) of the thermostat was 0.15°C. Since the massive apparatus could not follow such a rapid fluctuation in temperature, its constancy of position was affected only by the 0.05°C change, which was due to changes in heat flow through the walls and floor of the room.

In choosing an x-ray wave-length, the corrective factor A in Eq. (1) demands a short wave-length, but there is also the factor δ to be considered. From considerations of these factors and the actual measurements to be made, wave-lengths of about 1.0 to 1.5A appear best. Therefore the copper K_β line was used in the present experiments.

DENSITY OF DIAMOND

The density of the diamond was determined by measuring the density of a solution composed

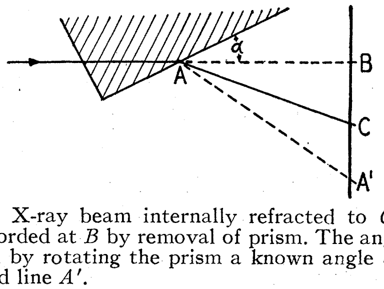

FIG. 2. X-ray beam internally refracted to C. Direct beam recorded at B by removal of prism. The angle α was measured by rotating the prism a known angle φ to give a reflected line A'.

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[3] J. A. Bearden, Phys. Rev. **37**, 1210 (1931).

of thallous formate and thallous molonate in which the diamond would neither sink nor float. The density of the solution was first made less than that of the diamond and placed in a glass tube bottle 30 mm in diameter and about 100 mm long, fitted with a ground glass stopper and evacuating tube. The diamond was then placed in the solution and the space above the solution evacuated. This removed all air bubbles from the diamond and increased the density of the solution by evaporation. The evacuation was continued until the density was slightly greater than that of the diamond. Air was admitted to the bottle and the latter placed in a large clear-sided thermos bottle filled with water at 23.50°C. Water was then added and mixed thoroughly with the thallous solution until the density at 23.5°C was very close to that of the diamond.

Since the expansion coefficient of diamond is extremely small, the density of the solution can be made equal to that of the diamond by adjusting its temperature. It was found possible to make the diamond float or sink with a difference in temperature of 0.03°C, which corresponds to a difference in density of the solution of less than 2 parts in 10^5. After accurately determining the temperature of the solution that corresponded to the density of the diamond, a 10 cc pycnometer was filled with the solution. The pycnometer was placed in the thermos bottle bath and after the temperature had attained equilibrium, the excess solution was removed. The volume of the pycnometer was determined by filling it with distilled water at the same temperature. The International Critical Table value for the density of water was used. Calibrated weights were used for all weighings and buoyancy corrections applied. Four similar pycnometers were used. The average of ten entirely independent sets of measurements gave

$$\rho=3.51536\pm0.00004 \text{ g/cm}^3 \text{ at } 23.5°\text{C}.$$

The probable error was calculated from the average deviation in the usual manner.

This result differs considerably from that of Tu[4] who obtained $\rho=3.5141\pm0.0001$ g/cm^3 and $\rho=3.5142\pm0.0001$ g/cm^3 on two perfect diamonds. Tu reported difficulty in making the diamonds sink or rise consistently, which indicated a non-uniformity of solution density. In the present work the thallous formate and thallous molonate solutions were carefully purified and passed repeatedly through asbestos pads held in a Gooch filtering crucible. No difficulty was experienced in making the diamond rise from the bottom to the top of the solution and back again with only a 0.03°C change in temperature.

In view of the large differences in density between the present results and those of Tu, six perfect diamonds ranging in size from one to seven carats were tested. The method used was to place the diamond used previously with one of the new ones in the thallous solution and then adjust the temperature as above until the diamonds would just rise or sink very slowly (about 2 cm/hr.). In all cases both diamonds rose and sank at the same rate. The sensitivity of the method is such that differences in density of 1 in 10^5 would have been easily detected.

While there appears to be no explanation of the discrepancy between the present densities and those of Tu, attention should be called to the fact that his density measurements on calcite crystals are also much lower than those of other experimenters. In a note to his Table XVI[4] comparing the results of different writers, he says that all values given have been reduced to 18°C, whereas only his value is given at 18°C. The others are copied from the original papers which were reduced to 20°C. This makes the difference between his results and the previous ones even greater. The Bureau of Standards has made careful determinations of the densities of the same crystals used in the previous work of the writer[5] and the average of their results is

$$\rho=2.71029 \text{ g/cm}^3 \text{ at } 20°\text{C},$$

which is in excellent agreement with the value 2.71026 obtained by the writer. Thus it appears that Tu made some systematic error in both the diamond and calcite densities. The errors are not sufficiently large to influence his conclusion concerning the nonexistence of a mosaic effect, but are of importance in precision calculations.

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[4] Y. Tu, Phys. Rev. **40**, 662 (1932).

[5] J. A. Bearden, Phys. Rev. **38**, 2089 (1931).

RESULTS

Figure 3 shows typical contact prints from enlargements made on positive film directly from the original plates. The lines were very sharp and well defined, which made it possible to measure them with an exceedingly high degree of accuracy. The exposure times which varied from one hour to twelve hours depended upon the thickness of the prism the x-rays had to traverse.

The 15 cm range precision comparator used for measuring the separations of the lines was carefully calibrated. The periodic error was determined by using a 300 power microscope and a good quality ruled grating. The absolute length calibration was made in a similar manner, by the use of a diamond ruled glass scale which had been calibrated by the Bureau of Standards. The separation of two diamond ruled lines could be remeasured on any part of the travel used within 0.0002 mm.

The separations of the lines on the photographic plates were measured at different points along the height of the lines and all measurements were repeated with the plate reversed in position. The average of the reversed measurements agreed with the initial ones within 0.002 mm and the average of the initial and reversed measurements for the different points along the line did not exceed 0.002 mm. There was also no consistent variation in the results with position along the height of the lines.

The results for the final series of 25 plates obtained with external incidence are given in Table I. The second column gives the thickness of prism traversed by the central ray, columns three and four are the average separations of the lines of the plates, and the fifth column gives the value of δ for each plate. From the agreement of the different sets of measurements, the probable error in δ for each plate is about 2×10^{-9}. The external consistency for the 25 results is 0.375×10^{-9} and the internal consistency is 0.4×10^{-9}. The ratio of these is as near unity as can be expected, and indicates that the only errors that could have influenced the value of δ more than 0.4×10^{-9} are consistent errors that occurred throughout all the measurements.

A good series of 15 plates was taken with internal incidence, and the average of these results was $\delta=9223\pm3$, but because of the extra-angular measurement that has to be made when this method is used, the results are not as accurate as those obtained with external incidence. These less precise results have not been used in evaluating e/m.

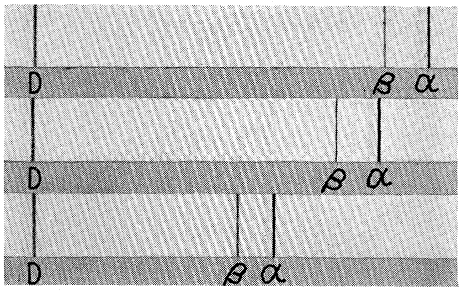

FIG. 3. Typical refraction spectra. D is the direct x-ray beam, α and β the refracted K_α and K_β lines of copper. The totally reflected line is not shown on the enlargement.

The measurement of the distance from the edge of the prism to the front of the photographic plate was taken three different times during the course of the experiment and all results agreed within 0.1 mm. This distance was measured by placing a long bar[6] with parallel ends between the prism and plate and then measuring the remaining distances (about 5 cm) with inside micrometers. Any consistent error of run in the comparator was certainly negligible. Since the pencil of x-rays struck the prism face at a very small angle, the rays which passed through the most material were more highly absorbed than those nearer the edge of the prism. However, the effective shift in the position of the refracted line can be easily calculated, and such a correction was applied to all the measurements in column three of Table I. It appears safe to assume a total error in δ of about 2.5 times the internal consistency, or

$$\delta=9224.4\pm1.0\times10^{-9}.$$

In the calculation of the value of e/m by Eq. (1) one must evaluate A from Eqs. (2) and (3). X_s is the ratio of the K critical absorption wave-length of carbon to the wave-length of the copper K_β line which was used in all the measurements recorded in Table I, or

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[6] The length of this bar was carefully measured by the National Bureau of Standards, Washington, D. C.

$X_s = 43.2$[7]$/1.3922$[8]$= 31.03$[9]; $N_s = 1.84$.[1]

These give for the $\sum_1^s$ in Eq. (1)

$$\sum_1^s N_s(1+A) = 6.0194 \text{ for a } \lambda^{2.5} \text{ law of absorption}$$

and

$$\sum_1^s N_s(1+A) = 6.0131 \text{ for a } \lambda^3 \text{ law of absorption.}$$

From an analysis of the available x-ray absorption measurements,[10] one finds the exponent of λ to be 2.75 ± 0.05. By interpolation, the $\lambda^{2.75}$ law gives

$$\sum_1^s N_s(1+A) = 6.0163 \pm 0.0006.$$

The other constants used in evaluating *e/m* are:

$\delta = (9224.4 \pm 1.0)10^{-9}$; W[11]$= 12.0148 \pm 0.0005$ g per gram mol. wt.,

$\rho = 3.5154 \pm 0.0001$ g/cm^3; F[11]$= 96513.1 \pm 8.0$;

$\lambda = 1.39220 \pm 0.00003$.

Thus the value of *e/m* from the present work is

$$e/m = (1.7601 \pm 0.0003) \times 10^7 \text{ e.m.u.}$$

The two most important sources of error in this value are the exponent of the x-ray absorption law and the experimental measurement of δ. The absorption measurements of S. J. M. Allen[10] have been plotted on a large scale and the ± 0.05 variation in the exponent of λ includes every measurement from 0.88A to 2.5A. The error in δ has been discussed above and appears to be conservative. The absorption term of the complete dispersion formula has been neglected, but this introduces a negligible error in the value of *e/m*.

A calculation[12] was made of the value of the refractive index by using the approximate wave-mechanical theory of Hönl, in order to see how much the result would differ from that of the other laws. The result for the K shell is that $N_k(1+A) = 1.876$, and the K oscillator strength, $N_k = 1.860$. When the wave-length is far to the short wave side of an absorption edge, A becomes negligible. Since A is so small for the K edge, it will surely be safe to neglect it for the L edge. From the *f* sum rule, neglecting double transitions as improbable, $N = 6 - N_k = 4.140$, so that

$$\sum_1^s = 1.876 + 4.140 = 6.016,$$

which is in very good agreement with the interpolated value of the $\sum_1^s$ above.

This result is not sensitive to small changes in the wave-length or in the wave-length of the K edge. A change of 1 percent in either makes a change in the final result of about 0.004 percent. The excellent agreement between this calculation

TABLE I.

PLATE	PENETRATION IN PRISM MM	DISTANCE $B-C$ IN MM	DISTANCE $B-D$ IN MM	$\delta \times 10^9$
48	0.87	3.9789	20.857	9220
49	1.11	3.1815	24.298	9221
50	1.84	4.2880	19.969	9222
51	0.80	3.5358	22.538	9225
52	1.09	4.6441	19.108	9220
53	1.30	5.0470	18.362	9222
54	3.02	3.3437	23.478	9222
55	1.81	3.7486	21.682	9220
56	1.84	4.2661	20.029	9223
57	0.50	2.8210	26.627	9224
58	1.11	4.2568	20.049	9227
59	0.98	3.9862	20.846	9226
60	1.16	3.9893	20.843	9228
61	1.16	3.7382	21.726	9229
62	0.50	3.1577	24.423	9223
63	1.19	3.3261	23.539	9228
64	0.51	3.5162	22.616	9224
65	0.72	4.2599	20.029	9224
66	1.03	3.0565	25.030	9219
67	1.07	4.2671	20.022	9226
68	1.19	4.2692	20.015	9225
69	1.38	4.2692	20.018	9226
70	1.71	3.7754	21.588	9225
71	1.58	3.7734	21.597	9227
72	1.43	3.7775	21.574	9224
				Average 9224.4±.04

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[7] Thibaud's value relative to Carbon K_α and the absolute scale of wave-lengths by M. Söderman, Phil. Mag. **10**, 600 (1930).

[8] J. A. Bearden, Phys. Rev. **47**, 883 (1935) for the ruled grating scale of wave-lengths, and the crystal wave-length from J. A. Bearden and C. H. Shaw, Phys. Rev. **48**, 18 (1935).

[9] X_s increases rapidly with atomic number. In the case of quartz and the copper $K_{\alpha 1}$ line, $X_s = 4$. The results obtained with the quartz prism (J. A. Bearden and C. H. Shaw, Phys. Rev. **46**, 759 (1934)) give a lower value of *e/m* than has been obtained with the diamond prism. The greatest uncertainty in the dispersion theory is in properly correcting for the electronic binding. In the case of quartz, where X_s is only 4, a small error in the correcting term would change the resulting value of *e/m* considerably more than in the case of diamond, where $X_s = 31$. This, and the uncertainty in the exponent of the x-ray absorption law for quartz, probably accounts for the difference between the diamond and quartz results.

[10] Compton and Allison, *X-Rays in Theory and Experiment*, p. 802.

[11] The writer is indebted to Professors R. T. Birge, K. T. Bainbridge, and H. C. Urey for information on the atomic weight of carbon, and to Professor Birge for the value of the Faraday.

[12] The writer is indebted to Dr. Russell Lyddane for making this calculation based on the Hönl theory.

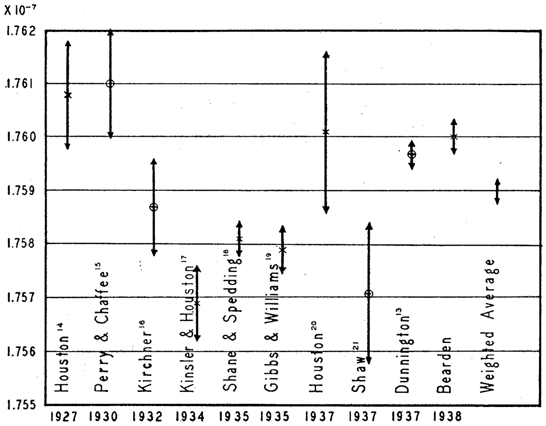

FIG. 4. A chronological plot of the best determination of e/m from 1927 to 1938. The bound electron results are indicated by ×, and the free electron by ⊖. Arrows show probable errors.

and the one above strongly supports the conclusion that adequate correction for electronic binding has been made in the present calculation of the value of e/m.

The present experiments differ markedly in one very significant way from all previous determinations, namely that in this case the electrons under observation are much more tightly bound. Here, then, is the opportunity to test whether bound and unbound electrons have different values of e/m, for the present value would be much lower than the free electron value if the binding is a significant factor. On the contrary, it is slightly higher than the excellent results of Dunnington[13] for free electrons, which seems to exclude the possibility of the value of e/m depending on the strength of electronic binding. The present status of the problem can be presented by plotting the recent values obtained by the various experimenters[13–21] together with their probable errors as in Fig. 4.

In the writer's opinion, the work of Dunnington should be given greater weight compared to other results. This has been done with the approval also of other workers in this field.

The weighted average of the bound electron results (crosses) is 1.7588×10^7 e.m.u., and that of the free electron 1.7596×10^7 e.m.u. If one compares the spectroscopic values (excluding the present results) with the free electron value, then there is a marked difference which appears greater than the experimental errors. The weighted average of all the results gives

$$e/m = (1.7590 \pm 0.0002) \times 10^8 \text{ e.m.u.}$$

A statistical analysis of the results gives for the ratio of external to internal consistency $R_e/R_i = 1.64$ for the spectroscopic and 1.01 for the free electron results, and 1.63 if all results are averaged. The 1.64 and 1.63 do not prove the existence of a discrepancy in the results, but it is high enough to invoke questions as to possible consistent errors or failure of theory in some of the methods used. The free electron results as obtained by Dunnington seem to be very sound, both in the theory of the method and in the experimental procedure. Likewise in the present work the dispersion theory for x-rays in diamond is sound and the experimental procedure is the simplest of any method. In the spectroscopic method one deals with unresolved components for which ample correction is difficult. It has been shown[19, 22] that the measured fine structure separation for $D\alpha$ and the spectroscopic theory are not in satisfactory agreement. This raises some question as to the precision of e/m calculated from spectroscopic data. The need for further spectroscopic work is obvious.

Since the above was written Dr. A. E. Shaw's complete article has been published. His final result and probable error are the same as is given in Fig. 4. This value differs from the writer's by one part in 600 which is about 1.5 times the sum of the probable errors. However, the sum of the probable errors is so large that no real discrepancy is indicated by a statistical analysis of the results.

The writer is greatly indebted to the Rumford Committee of the American Academy of Science for funds with which to purchase the diamond prism. He is also grateful to Mr. C. M. Herget, who assisted in the determination of the densities of the diamonds, and to Dr. C. H. Shaw for helpful discussions and assistance.

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[13] F. G. Dunnington, Phys. Rev. **52**, 475 (1937).

[14] W. V. Houston, Phys. Rev. **30**, 608 (1927).

[15] C. T. Perry and E. L. Chaffee, Phys. Rev. **36**, 904 (1930).

[16] F. Kirchner, Ann. d. Physik **8**, 975 (1931); **12**, 503 (1932).

[17] L. E. Kinsler and W. V. Houston, Phys. Rev. **45**, 104 (1934); **46**, 533 (1934).

[18] G. D. Shane and F. H. Spedding, Phys. Rev. **47**, 33 (1935).

[19] R. C. Gibbs and R. C. Williams, Phys. Rev. **48**, 971 (1935).

[20] W. V. Houston, Phys. Rev. **51**, 446 (1937).

[21] A. E. Shaw, Phys. Rev. **51**, 887 (1937).

[22] W. V. Houston, Phvs. Rev. **50**, 392 (1936).

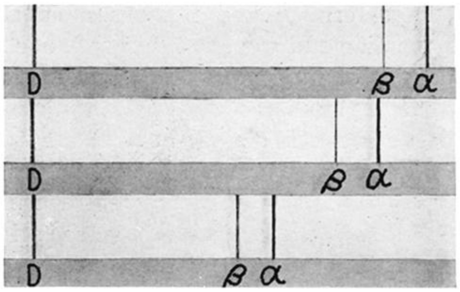

FIG. 3. Typical refraction spectra. D is the direct x-ray beam, α and β the refracted K_α and K_β lines of copper. The totally reflected line is not shown on the enlargement.