been represented. A direction of magnetization, of form $<111>$, has been assigned at random to each block. About half of them therefore have a component of **I** up from the paper. A black dot has been placed in the appropriate corner of each such square in the left-hand diagram. These dots would be enhanced by an applied field toward the observer. The rest of the squares have a component of **I** into the paper. A black dot has been placed in the appropriate corner of each such square in the right-hand diagram. These dots would be enhanced by an applied field away from the observer. The halves of Fig. 2 are reciprocal in the same sense as the halves of Fig. 1, but show even fewer collineations and other groups. If the suggested model is at all similar to the actual magnetic structure of a polished nickel surface it seems probable that the magnetization of adjacent blocks is not completely independent.

L. W. McKeehan
W. C. Elmore

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August 14, 1934.

[1] L. W. McKeehan and W. C. Elmore, Phys. Rev. [2] **46**, 226 (1934).
[2] Grown by the method described by S. L. Quimby, Phys. Rev. [2] **39**, 345–353 (1932).

High Energy Gamma-Rays from Lithium and Fluorine Bombarded with Protons

We have shown that some of the light elements, when bombarded with protons or deutons emit γ-rays, and we have in several instances measured the absorption coefficient of the radiation in lead, and from this attempted to estimate the quantum energy. Recently Professor Oppenheimer has called our attention to the fact that, owing to the rapidly increasing probability of pair production with increasing quantum energy the quantum energy of a γ-ray is not always uniquely determined by the absorption coefficient in a single substance. This is seen from Fig. 1,

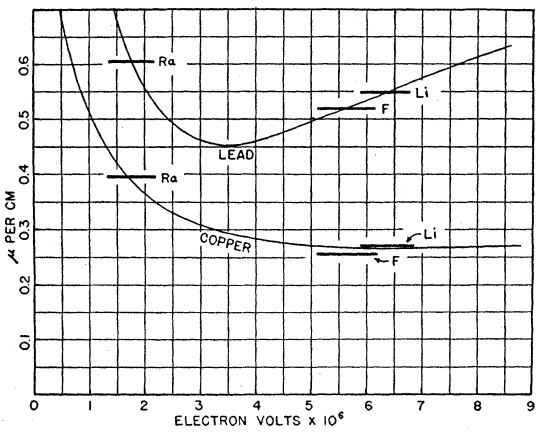

FIG. 1. Total absorption coefficient (Klein-Nishina + photoelectric + pair) of γ-rays in lead and in copper, as a function of their quantum energy.

which shows the total absorption coefficient for γ-rays in lead and in copper, as a function of quantum energy, plotted from theoretical figures kindly supplied us by Professor Oppenheimer.

In confirmation of this double valued absorption coefficient McMillan[1] has reported γ-rays from fluorine bombarded with protons and has shown, by measurements in various substances, that their absorption coefficients are correctly predicted by the theory if the quantum energy is about 5.5 m.e.v.

This consideration made it desirable to reinvestigate some of the γ-rays upon which we have previously reported, by making absorption measurements in at least one substance in addition to lead. This we have done in the case of the γ-rays emitted by lithium and by fluorine* bombarded with protons,[2] using lead and copper absorbers. The absorption coefficients found are indicated by horizontal lines intersecting the theoretical curves in Fig. 1. A correction for scattering has been applied to these values, and will be discussed below. Although the absorption coefficients in lead of these γ-rays are not very different from that of radium γ-rays, it is clear from the corresponding absorption coefficients in copper that their quantum energy is such as to place them on the high energy side of the minimum, at about 6.3 m.e.v. for lithium, and 5.6 m.e.v. for fluorine, rather than on the low energy side, as we previously supposed.

It is difficult to estimate the correction to be applied for scattering, over such a wide range of energy, especially where the mechanism of absorption is different at the high and the low energies. With the present experimental set-up we find an apparent absorption coefficient for radium γ-rays which is about 10 percent too low. However, while the attenuation of the radium γ-rays is due primarily to Klein-Nishina scattering, only about 40 percent of the attenuation of the 5.6 m.e.v. radiation from fluorine is due to Klein-Nishina scattering and the remaining 60 percent to pair formation. The 60 percent absorbed in pair formation contributes no scattered radiation directly, since the quantum is supposedly completely absorbed, but the resulting high velocity positive and negative electrons, in traversing the lead, give rise to some continuous x-radiation, in addition to the two 0.5 m.e.v. quanta resulting from the ultimate annihilation of the positron. Since in the high energy region this latter radiation tends to compensate for the smaller amount of scattered radiation, we have retained the 10 percent correction found for radium γ-rays, and have applied it uniformly to all our data.

In order to obtain the quantum energy of the above γ-rays in an independent way, and to check the theoretical absorption curves, we have undertaken to investigate by means of a cloud chamber the energy spectrum of negative and positive electrons ejected from a lead plate.

Fig. 2 shows the energy spectrum of the negative and positive electrons ejected from a 3 mm lead plate by the radiation from CaF_2 bombarded with 0.8 m.e.v. protons. The energies were determined by measuring the curvature in a magnetic field of 1200 gauss. A total of 641 measurable tracks above 0.5 m.e.v. were obtained; 434 negatives and 207 positives. From these curves we find, after applying

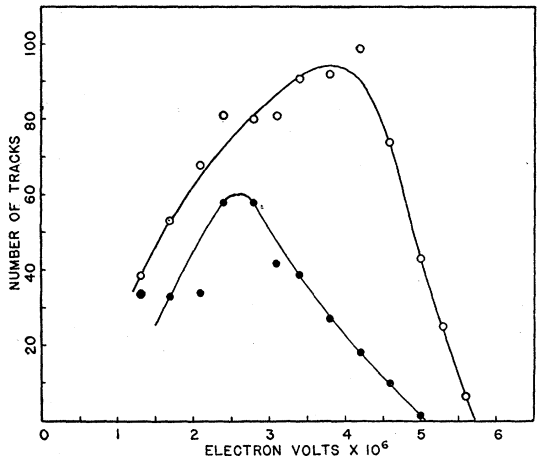

FIG. 2. Energy spectra of positive and negative electrons ejected from a thick lead plate by the radiation from fluorine bombarded with protons. Dots refer to positives, and circles to negatives, each representing the number of electrons in a 0.7 m.e.v. energy interval.

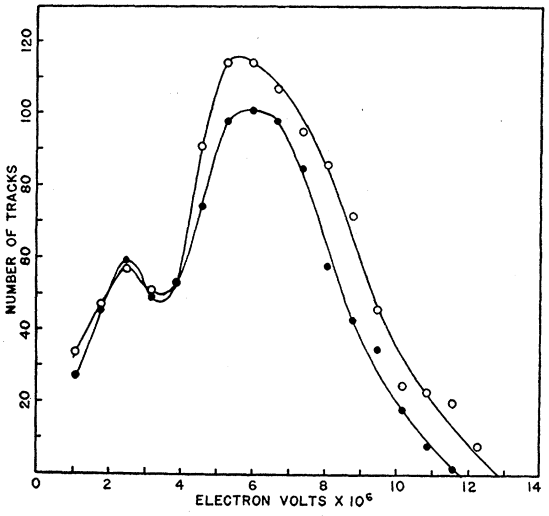

FIG. 3. Energy spectra of positive and negative electrons ejected from a thick lead plate by the radiation from lithium bombarded with protons. Dots refer to positives, and circles to negatives, each representing the number of electrons in a 1.4 m.e.v. energy interval.

appropriate corrections,[3] 5.4 m.e.v. as the quantum energy of the γ-ray. It is reasonably certain that no other γ-ray of comparable intensity is present above 2 m.e.v. No tracks below 1 m.e.v. were plotted, because of the larger errors which might be introduced. The value of the energy obtained is in agreement with the value obtained by absorption measurements, both by McMillan and by ourselves (see Fig. 1).

In Fig. 3 is shown the energy spectrum obtained under the same conditions with LiCl bombarded with protons. In this case 956 measurable tracks above 1.0 m.e.v. were obtained; 521 negatives and 435 positives. The distribution indicates with certainty a γ-radiation of approximately 12 m.e.v. and apparently a second component of about 4 m.e.v. In spite of the fact that the second component is much less conspicuous in the diagram, it must be of intensity comparable to that of the 12 m.e.v. component for several reasons: (1) Because of the shorter range of the electrons, a smaller effective thickness of lead is made use of. (2) A smaller number of electrons are produced in a given volume of lead because of the lower absorption coefficient. (3) The 4 m.e.v. component will be to some extent masked by the slower electrons and the softened radiation resulting from the 12 m.e.v. component.

The absorption coefficient for the radiation in lead (Fig. 1) corresponds to about 6.3 m.e.v., and this is not inconsistent with a composite radiation consisting of roughly equal intensities of 12 and 4 m.e.v. components, as suggested by the electron spectrum. No exact comparison is possible, since the relative intensities are not accurately known.

It is seen in Figs. 2 and 3 that the high energy limit of the negative electrons is roughly 1 m.e.v. higher than that of the positive electrons,† and this is consistent with the theory of pair formation. On the assumption that the number of negatives belonging to pairs is equal to the number of positives, and that the positives and negatives resulting from pairs have essentially the same initial energy spectrum, we can subtract the number of positives from the total number of negatives to find the number of negatives which do not belong to pairs. Further, since the average energy of a member of a pair is somewhat less than half that of a photoelectron or a forwardly directed Compton recoil electron, the effective thickness of lead contributing members of pairs is less than half that contributing single negatives. Therefore to find the number of pairs formed per unit volume relative to the number of single negatives, we must multiply the number of positives observed by a factor of approximately 2. This gives, for the 5.4 m.e.v. radiation, 1.8 pairs per single negative, and for the 12 m.e.v. radiation, 10 pairs per single negative, and this is in good agreement with Oppenheimer's theoretical calculations.

The shape of the high energy side of the observed positive electron spectrum is well accounted for if we assume that when a pair is produced the energy of the quantum is most likely to be shared equally between the positive and negative electron, and the probability of unequal division of energy decreases roughly linearly with the departure from equality, until the probability that one member receives all of the energy is practically zero. That the curve drops off on the low energy side is due to the fact that many of the electrons originating below the surface fail to come out because of the high probability of large angle scattering and consequent large energy loss in the lead. For the same reason we must expect that only comparatively rarely will both members of a pair be observed when thick lead is used. Although we have observed relatively few pairs in our experiments with thick lead, in preliminary observations using thin lead, pairs are relatively much more frequently observed.

We wish to express our appreciation to Professor J. R. Oppenheimer and to Professor R. C. Tolman for many

helpful discussions in connection with this work, and to the Seeley W. Mudd Fund financial support.

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August 16, 1934.

[1] McMillan, Am. Phys. Soc. Meeting, Berkeley, June 18–23, 1934.
* Targets of LiCl and CaF_2 were used, and $CaCl_2$ was bombarded to make sure that neither Ca nor Cl gave an appreciable effect.
[2] Presented at the Berkeley meeting of the Am. Phys. Soc., June 18–23, 1934.
[3] Chadwick, Blackett and Occhialinni, Proc. Roy. Soc. **A144**, 235 (1934).
† If no photoelectrons are observed, as may be the case at these high energies, the difference between the maximum energies of the positive and negative will be only 0.78 m.e.v., due to the fact that the energy of the fastest Compton recoil must be 0.24 m.e.v. less than the quantum energy of the γ-ray.

Zeeman Effect in Neon

A measurement of the Zeeman splitting of two neon lines has been carried out with two purposes in view. One was to obtain a value of e/m; and the other was to investigate with high precision the validity of the g-sum rule in a particular case. The apparatus and method are essentially the same as previously described for the determination of e/m from measurements of the Zeeman effect in Zn and Cd.[1] A determination from neon lines was desirable since no theoretical correction factor needs to be applied, and since neon's spectral type is different from that of zinc and cadmium.

The g-sum rule states that the sum of the Landé g-values for all the levels in one electronic configuration which have the same J-value is the same for all types of coupling and for all magnetic field strengths. The neon lines λ5852 and λ6074 were found to be sufficient to make a precise check of this rule. Table I contains information regarding these

TABLE I.

λ5852		λ6074	
$2p^5\,3s\,{}^1P_1-2p^5\,3p\,(2p_1)$		$2p^5\,3s\,{}^3P_1-2p^5\,3p\,(2p_3)$	
$g=1.000$	$g=0/0$	$g=1.500$	$g=0/0$
$J=1$	$J=0$	$J=1$	$J=0$

lines. The g-values given are those calculated from Russell-Saunders coupling. As may be noticed in any table of spectroscopic levels[2] these levels are the only ones in their electronic configurations with the respective given J-values. Consequently, the g-sum rule may be applied.

By assuming that no splitting takes place in a magnetic field for the levels with $J=0$, the values of g for the levels with $J=1$ were found to be

Line	No. Plates Meas.	g
5852	13	1.0350 ± 7
6074	15	1.4667 ± 9

In order to compute these values of g, the value of $e/m=1.7570$ was used. The sum of these values is then 2.5017 ± 0.0016 which agrees with 2.5000 to within the experimental error. Therefore it seems that in this case the g-sum rule is valid to better than 0.1 percent.

If instead of assuming a value of e/m, one assumes the validity of the g-sum rule, the value of e/m is found to be $e/m=1.7580\pm0.0014\times10^7$ e.m.u./g. This value is in satisfactory agreement with other values obtained from the Zeeman effect.

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California Institute of Technology,
August 20, 1934.

[1] L. E. Kinsler and W. V. Houston, Phys. Rev. **45**, 104 (1934).
[2] Bacher and Goudsmit, *Atomic Energy States*.

Zeeman Effect in Helium

Since publishing an abstract[1] regarding an anomalous Zeeman splitting of three helium singlet lines, λ6678, λ5015 and λ4921, the cause of this anomaly has been found to be experimental. Photographs of the helium line interference patterns were taken with the same apparatus and in much the same manner as has been described for Zn and Cd.[2] The constriction in the discharge tube from which the spectrum originated was cooled by a surrounding jacket into which liquid air was blown. This reduced the line widths by some 40 percent. However, it was necessary to make microphotometer records of the original plates in order to adequately measure the separation of the two displaced σ components.

The error in the previous results was caused by the presence of the undisplaced π component at 30 times the intensity expected from the angle subtended at the source by the condensing lens. This increased intensity has subsequently been shown to be caused by scattered and reflected light. Presence of a weak π fringe between every pair of σ fringes in the interference pattern caused the maxima of the latter to be displaced and led to the published erroneous results. Such a difficulty arises only for broad lines such as those of the light elements since for heavy elements this component is resolved.

It was found possible to eliminate this component by placing a 1 mm×4 mm slit at the re-entrant window of the discharge tube and painting the remainder of the tube black. Consequently, no scattered or reflected light could reach the slit of the spectrograph. In the results that follow six or more plates at different magnetic field strengths were measured for each line.

Line	Value of e/m
6678	$1.7570\pm0.0007\times10^7$
5015	$1.7552\pm0.0010\times10^7$
4921	$1.7568\pm0.0011\times10^7$

By giving the result for λ6678 double weight the average value of e/m is $1.7564\pm0.0009\times10^7$. λ6678 was given greater weight because the interferometer spacing was three times that for the other lines which resulted in greater resolution and since the π component had been more completely eliminated. The deviation of λ5015 is in such a direction as to be explained by the possible presence of the π component.

The values of e/m obtained with this apparatus from four elements by measurement of the Zeeman splitting of their