ionization is however equal to the minimum ionization produced by particles with $z=1$, i.e., electrons and protons. The energy which gives this minimum is $3Mc^2$, i.e., 1.5×10^6 volts for electrons, and 3×10^9 volts for protons. From other evidence the ionizing particles of penetrating radiation have energy at least of the order of 10^9 volts. Electrons are therefore ruled out, but not protons.

It is interesting to note that the total ionization observed by Skobelzyn (40/cm) is equal to the theoretical primary ionization due to electrons with about 10^{10} volts. The writer, who has for some time been aware of the position concerning this question,[7] wrote to Dr. Skobelzyn, some time ago (Nov. 1929), to make sure that the ionization observed by him was not conceivably primary ionization, in which case it would follow that the particles concerned might be 10^{10} volt electrons. In his reply Dr. Skobelzyn however confirmed the statement in his paper.

We must mention recent observations of a similar kind to Skobelzyn's made by Mott-Smith and Locher.[9] Carlson and Oppenheimer conclude from these that the particles concerned cannot be any known electric particle. The experimental data are however too qualitative for such a conclusion to be drawn. In fact, as far as it goes, the data are not inconsistent with Skobelzyn's, and it therefore leaves the above conclusions unaffected. Mott-Smith and Locher say that the 'penetrating' particles they observe produce about one half of the ionization produced by an average recoil electron from scattered hard $RaC\gamma$ rays. The latter is very indefinite. A rough estimate gives a total ionization by such recoil electrons of about 90 per cm, and half this agrees with Skobelzyn's result of 40/cm. This agreement however confirms no more than the order of magnitude of the results.

e. Heavy collisions. The primary ionization, and d_WT, depend only on light collisions. To obtain the energy lost in all collisions we must add to d_WT a quantity $d^WT=\int_W^{Q_{\max}}Q\phi(Q)dQdx$. This integral involves large Q for which magnetic forces and relativity variation in the mass of the "knocked" electron may be important—these effects are neglected in the treatment of light collisions in *c*, Carlson and Oppenheimer state that the contribution of the heavy collisions to the total stopping power is unimportant. Now as far as protons (and heavier particles) are concerned, the problem of the loss of energy in traversing free electrons* is the same as the problem of the nuclear scattering of electrons, which has already been worked out on the quantum theory by Mott.[10] Using Mott's results we find that for very heavy particles, except for Q close to its maximum value of $2\epsilon^2mc^2$, $\phi(Q)$ is the same as its nonrelativity value $\phi_0(Q)$ given by (6). It follows that if ϵ is very large, d^WT/dx is approximately $(2\pi Nz^2e^4/mc^2)\log(\epsilon^2mc^2/W)$. Adding this to d_WT/dx (Eq. (3)) we obtain a total dissipation of

$$dT/dx=(4\pi z^2e^4N/mc^2)\{\log(mc^2/E)+2\log\epsilon\} \quad (7)$$

According to this and (2) the dissipation for *very* large ϵ is just doubled by the inclusion of heavy collisions—in contradiction with the above supposition of Carlson and Oppenheimer.

It is surprising that $\phi(Q)$ maintains the same form for $Q\gg mc^2$ as for $Q\ll mc^2$, since for the former the knocked electron is effectively a heavy particle. A change in the region $Q\sim mc^2$, however, requires a change in the nuclear scattering formula in the region of scattering angle $\theta\sim(1-\beta^2)^{1/2}$, and in Mott's formula there is no such change. The contribution of heavy collisions is negligible only if the scattering is negligible for $\theta>(1-\beta^2)^{1/2}$.

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January 26, 1932.

[7] E.g., reference, 2, p. 336.

[8] Skobelzyn, Zeits. f. Physik **54,** 686 (1929).

[9] Mott-Smith and Locher, Phys. Rev. **38,** 1399 (1931).

* In the region $Q>W$ the atomic electrons may be treated as free since $W\gg J$.

[10] Mott, Roy. Soc. Proc. **A124,** 425 (1929).

Zeeman Effect in the Spectrum of Pb III.

We have been studying the Zeeman effect of the spectra of Pb II, Pb III, and Pb IV with a view to checking the classifications in these spectra. The patterns found are in general agreement with the classification of Gieseler[1] on Pb II and Smith on Pb III[2] and Pb IV.[3]

Of these spectra, Pb III is the most interesting, since we have the possibility of checking the Houston[4] theory of intermediate coupling. In the case of the $6s7p$ configuration, $(^3P_0, {}^3P_1, {}^3P_2, {}^1P_1)$ the g-sum of $^3P_1+{}^1P_1$ yields a value slightly higher than the 5/2 it should be according to Pauli's g-sum rule, while the $^3P_2$ level, which should be unaffected by coupling (to first order terms) yields a g-value of about 1.35 instead of 3/2. This might be accounted for by incorrect assignment, but there is no other level in the neighborhood that would fit. It seems then, that the abnormal g-value must be attributed to perturbations caused by the proximity of $6p^2$ and $6s7d$ configurations.

The work was done with the aid of the new 30,000 line 21-ft. grating in the Paschen-Ruage mounting, and the Weiss-type magnet recently completed at this laboratory, with fields of about 41,000 gausses. A complete report will appear in the late summer.

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[1] Gieseler, Zeits. f. Physik **42**, 265 (1927).
[2] Smith, Phys. Rev. **34**, 393 (1929).
[3] Smith, Phys. Rev. **36**, 1 (1930).
[4] Houston, Phys. Rev. **33**, 297 (1929).

Attempts to Induce Temporary Radioactivity in Matter

The experiments of Pokrowski,[1] which report the excitation of feeble radioactivity in heavy elements by irradiating them with x-rays, are of such an astonishing nature that they seem to warrant careful repetition. Gingrich[2] did not find the ionization effects, on repeating the work with detecting apparatus of higher sensitivity and with harder x-rays and irradiating the materials for longer times. This naturally casts doubt on the existence of the effect, although Pokrowski seems to have taken such careful precautions in his experiments that it is not easy to see where consistent error could have been introduced. Pokrowski found measurable ionization produced as long as 90 minutes after exposure of the specimen to x-rays, and suggested that the energy was released from nuclei by trigger-action of the photons. Even if this dubious process is admitted as possible, one might expect that the emission would only last for a very small fraction of a second after irradiation of the specimen ceased. On the other hand, if nuclei have definite eigenstates, similar to those involving extranuclear electrons, it seems reasonable to believe that the absorption of suitable gamma-radiation might cause transitions which would subsequently result in nuclear fluorescence, even from non-radioactive atoms.

I have recently completed several series of experiments in which *long-time fluorescence* was sought from various materials that had been irradiated with gamma-rays and x-rays of different wave-lengths. No such fluorescence was detected, although the intervals between irradiation and detection ranged from 7×10^{-5} sec. to an hour. A Geiger counter was used as a detector. Its approximate sensitivity was found from the increase in the counting rate due to a known amount of radium at a known distance. The "accidental" count was 110 per hour, with the shielding used, while the rate with 1 mg of radium at 4 meters was 700 per hour. From this it is deduced that the accidental counting rate would be increased 50 percent by 2.3×10^{-6} mg of radium 2 cm from the counter, or that 4.6×10^{-8} mg would give a 1 percent increase. The sensitivity, expressed as the minimum detectable radium equivalent, depends on the distance of the material from the counter and the total number of impulses counted, hence the length of time over which the count is made.

In the first gamma-ray tests, various metals and crystals were irradiated for intervals up to an hour with gamma-rays from 1 mg of radium, at 3 mm distance, and transferred to the counter in about 30 sec. No increase in the counting rate was observed; the sensitivity of the counter was about 10^{-6} mg. The substances tried included aluminum, copper, lead, calcite, rocksalt, potassium bichromate, zinc sulphide, and quartz. The lead was a container for the radium, so had been exposed to gamma-rays for more than a year.

To test for fluorescence lasting for much shorter times, a beam of gamma-rays from 1

[1] G. I. Pokrowski, Phys. Rev. **38**, 925 (1931); also, Ann. d. Physik **9**, 505 (1931).
[2] N. S. Gingrich, Phys. Rev. **39**, 748 (1932).