width of the experimental curve should be the sum of the two widths. Therefore, the failure of this rule[4] must be linked with the failure of the original curves to be witches. The exact law of correction, then, should depend on the departure from the witch and hence on the constant C. This should be determined by using moderate values of x, as the effect on the width is negligible for large values of x.

Roy C. Spencer

Brace Laboratory of Physics,
University of Nebraska,
November 20, 1934.

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[1] Parratt, Rev. Sci. Inst. **5**, 395 (1934).
[2] Hoyt, Phys. Rev. **40**, 477 (1932).
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[4] Parratt, Phys. Rev. **46**, 749 (1934).

Rectifying Effect in Chrome Cast Iron

I recently noted an apparent rectifying effect in chrome cast iron similar to that of the "Kuprox" rectifiers.

In melting the metal, which contained about 14 percent chromum and 2 percent carbon, it was made the anode in a 220 volt d.c. arc furnace; a graphite rod serving as cathode. When fusion was nearly complete, current was accidentally shut off and the metal cooled. Its surface was badly oxidised as a result of opening the furnace while still hot.

On attempting to start the arc again it was found that no current would pass. But after reversing the polarity so that the metal became the cathode, current readily passed, an arc was struck and the metal was heated to seven or eight hundred degrees in this manner. It was then found that current would again pass in the original direction.

The metal was contained in a magnesia-lined bowl through the bottom of which a steel bar extended, serving as conductor. The cathode extended vertically downward through a hole in the cover.

I have seen no notice of such a rectifying effect in chrome cast iron; which effect seems rather strange in view of the fact that the black iron oxide which is formed on hot iron is a conductor even when cold. The effect seems to have been due to the presence of the chromium, whose oxide (Cr_2O_3) does not conduct until heated to a temperature in excess of one thousand degrees. On the other hand I have noticed that some chromium-iron ores which are relatively rich in iron conduct very readily when cold. Time was not available in which to investigate this phenomenon further.

Leo G. Hall

Spalding Machinery Company,
Chicago, Illinois,
November 24, 1934.

Gamma-Rays from Boron Bombarded with Deutons

Using a Wilson cloud chamber in a magnetic field of 1000 gauss we have studied the spectrum of recoil electrons produced by the gamma-rays from boron bombarded with deutons, and have found it to consist of components of at least five different energies.

A total of 6500 photographs was obtained, of which 1500 were taken with a carbon sheet 1 mm thick across the center of the chamber, 4000 with a 0.25 mm lead sheet, and 1000 with a 3 mm lead sheet. Where the thin absorber was used, it was possible to identify the tracks of recoil electrons and electron pairs which originated in the thin material. Below are shown the energy spectra of the electrons from the thin carbon absorber (Fig. 1), and of those ejected in the forward direction from the glass walls of the chamber (Fig. 2).

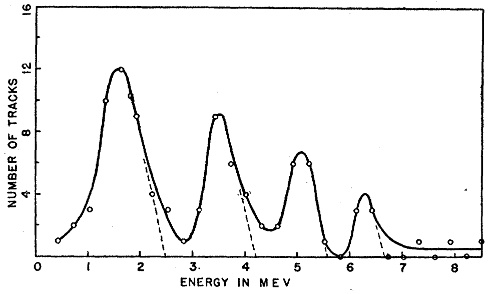

Fig. 1. Energy spectrum of negative electrons ejected from a 1 mm carbon absorber by the gamma-radiation from boron bombarded with deutons. Ordinates represent the number of tracks in a 0.3 m.e.v. energy interval.

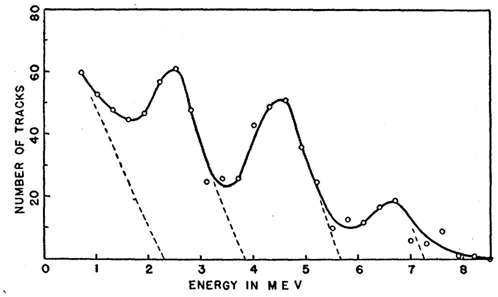

Fig. 2. Energy spectrum of negative electrons ejected from the glass wall of the chamber by the gamma-radiation from boron bombarded with deutons. Ordinates represent the number of tracks in a 0.3 m.e.v. energy interval.

The spectrum in Fig. 1 indicates gamma-ray lines of roughly 2, 4, 5.5 and 7 m.e.v., the intercepts of the curves extrapolated down to the axis being 2.4, 4.2, 5.6 and 6.7 m.e.v., and in addition an appreciable number of tracks of higher energy, extending up to more than 10 m.e.v. The spectrum from the thick glass absorber (Fig. 2) indicates the same lines, and is less subject to statistical fluctuation, since it is composed of a larger number of tracks. It gives intercepts at 2.3, 3.9, 5.6 and 7.2 m.e.v. Here, however, the 2 and 4 m.e.v. lines are not so clearly resolved, and the extrapolation of the 2 m.e.v. line down to the axis obviously cannot be accurate. The presence of four lines of approximately the above energies is further confirmed by the spectra of electrons and of electron pairs from the lead absorbers, the plots of which are not shown. Tracks of very high energy appeared relatively more frequently when the lead absorber was used, and a number of pairs were found having total energies as high as 10 m.e.v.

The 2, 4 and 7 m.e.v. lines can be correlated with differences in energy of proton groups observed by Cockroft and Walton,[1] which indicate lines at 2.2, 4.5 and 6.8 m.e.v. The reaction producing the protons, and hence also these gamma-ray lines is probably

$$B^{10}+H^2\rightarrow B^{11}+H^1. \qquad (1)$$

The 5.5 m.e.v. line has been found associated with the formation of C^{12} in the case of beryllium bombarded with alpha-particles,[2] and therefore it seems reasonable to ascribe it also in this case to the reaction in which C^{12} is produced:

$$B^{11}+H^2\rightarrow C^{12}+n^1. \qquad (2)$$

Alpha-particles are produced, by the reaction

$$B^{10}+H^2\rightarrow 3\ He^4 \qquad (3)$$

with a large excess of energy, and it is probable that this is responsible for the component of radiation observed at 10 m.e.v. or higher. There has already been an indication that the alpha-particle has an excitation level at about 12 m.e.v.,[3] and the present observations furnish confirmation of this hypothesis.

The absorption coefficient in lead which we previously determined for the gamma-radiation from boron bombarded with deutons[4] is entirely consistent with the above combination of lines, if we keep in mind the fact that the absorption coefficient for lead has a minimum at about 3 m.e.v. and rises for energies higher than this.[5]

Also the ratio of positive to negative electrons (0.05) from the thin lead absorber is the same as would be produced by a single gamma-ray line of about 5 m.e.v., and is therefore consistent with the mixed radiation in question.

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H. R. Crane
L. A. Delsasso
W. A. Fowler
C. C. Lauritsen

Kellogg Radiation Laboratory,
California Institute of Technology,
December 1, 1934.

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[3] Lauritsen and Crane, Phys. Rev. **46**, 537 (1934).
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Capture of Charged Particles by Nuclei Due to Emission of Gamma-Radiation

According to the experiments of Lea[1, 2] and more definitely according to Chadwick and Goldhaber[3] a proton and a neutron may unite to form a deuton emitting a γ-ray in the process. It appears probable that a nucleus and a proton may unite also in other cases, and that the excess energy may be emitted as γ-radiation. Thus, the formation of N^{13} by proton bombardment of C may perhaps be due to the reaction $C^{12}+H^1\rightarrow N^{13}+\gamma$. We calculated the probability of such processes, and we can account without difficulty for collision cross sections of the order of 10^{-30} cm² and higher for 500 kv protons supposedly captured by C with the emission of approximately 7×10^6 e.v. γ-rays. We discuss first an approximate formula for the effective collision cross section σ at a given velocity v of the protons

$$\sigma=5.08(c/v)(1+\eta^2)(R^5/\lambda^3\Lambda^2)P^2\cdot\pi R^2\xi/(e^\xi-1). \qquad (1)$$

Here

$$P=1+(5/12)\kappa R\eta+(1/14)(\kappa R\eta)^2(1-1/\eta^2)$$
$$+(1/144)(\kappa R\eta)^3(1-7/2\eta^2)+\cdots,$$

$$\eta=Zc/\text{“}137\text{”}v,\quad \xi=2\pi\eta,\quad \kappa=2\pi/\Lambda,\quad \Lambda=h/mv.$$

λ = wave-length of γ-rays, Λ = wave-length of incident protons, R = nuclear radius. This formula is rough, but is often useful in estimating σ. Two approximations are involved in its derivation: (1) that of neglecting the effect of the nuclear potential well on the wave function of the proton before capture, (2) that of taking the wave function of the proton after capture to be constant through a sphere of radius R and zero outside that sphere. The values of σ obtained from this formula for 520 kv protons incident on carbon for $h\nu=14mc^2\cong7\times10^6$ e.v. are:

σ(cm²)	$=1.3\times10^{-28}$	2.2×10^{-29}	2.3×10^{-30}	1.0×10^{-31}	6.1×10^{-34}
for R(cm)	$=1.0\times10^{-12}$	0.8×10^{-12}	0.6×10^{-12}	0.4×10^{-12}	0.2×10^{-12}.

The dependence on v is primarily determined by $e^{-\xi}$. The mean collision cross section for solid targets is

$$\bar{\sigma}=v^{-3}\int_0^v 3\sigma(v)v^2dv.$$

For $R=0.4\times10^{-12}$ cm. The ratio $\bar{\sigma}/\sigma$ has the approximate values 0.26 at 1020 kv and 0.34 at 520 kv.

The above formula is simple but not accurate. Without approximations except those inherent to a central field treatment one finds for the dipole radiation due to a transition to a captured s state:

$$\sigma=3.36\frac{c}{v}\frac{1+\eta^2}{(\kappa\lambda)^3}\frac{\xi}{e^\xi-1}\cdot\frac{1}{\kappa^2}\left|\int_0^\infty\rho\Psi(\rho)\bar{f}_1(\rho)d\rho\right|^2, \qquad (2)$$

where Ψ represents the captured state, $\rho=\kappa r$, $\int\Psi^2(\rho)d\rho=1$ and $\bar{f}_1$ is the function which replaces the regular power series solution in a Coulomb field beginning with ρ^2 for $l=1$. If the well is absent $\bar{f}\rightarrow f=\rho^2(1+\cdots)$. The ratio $|\bar{f}/f|^2$ at boundary of well is $[(1-FG\delta)^2+F^4\delta^2]^{-1}_{r=R}$, where F, G are, respectively, the regular and irregular radial functions asymptotic at ∞ to $\sin(\rho+\epsilon)$, $\cos(\rho+\epsilon)$. The quantity $\delta=(F'/F-\bar{f}'/\bar{f})$.

Formula (2) gives larger values of σ than Eq. (1). Thus for a well with a depth of about 20×10^6 e.v. and a radius $R=0.33\times10^{-12}$ cm the approximate values of σ are as follows:

Energy (kv)	900	730	580	440
$\sigma(10^{-30}$ cm²)	3.9	2.7	1.7	0.94

The more accurate Eq. (2) gives a less rapid decrease of the