In another experiment, 0·1–0·3 c.c. of 0·1 per cent œstrone in corn oil was placed in one horn of the uterus of each of six adult castrate female rats, escape of the oil being prevented by ligation of the uterus; the animals had previously been treated with moderate doses of œstrone intraperitoneally in order to distend the uteri. The animals were killed on the fourth day after filling the uterus; the œstrin-treated horn showed signs of commencing metaplasia in three cases and complete metaplasia to stratified squamous epithelium in one case.

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Production of Electron-Positron Pairs

THE production of a pair of positive and negative electrons by two photons was one of the consequences of his theory of the electron first considered by Dirac. This effect is essentially at the basis of all pair production phenomena, and it may be of interest to point out that from the formula for it, recently given by Breit and Wheeler[1], we may readily deduce, to a certain approximation, the probabilities for the production of pairs by high-energy photons and electrons in the field of an atomic nucleus. The correlation of these effects depends on the fact that for an observer moving relative to a nucleus with a velocity approaching that of light, the field of the nucleus is approximately equivalent to a radiation field. In the region effective for producing pairs—at distances from the nucleus of the order of and greater than $\hbar/mc$—the nuclear field corresponds, for an observer travelling with velocity v, to a distribution of photons the number of which in the frequency interval $d\nu$ is given by

$$N(\nu)d\nu = (2/\pi)\alpha Z^2 \log (g\gamma mc^2/h\nu)\, d\nu/\nu \qquad (1)$$
$$\alpha = e^2/\hbar c, \quad \gamma = (1 - v^2/c^2)^{-1/2}, \quad g \sim 1.$$

The cross-section, σ, for pair-production by a photon, $h\nu$, of energy ξmc^2, $\xi \gg 1$, is now obtained by considering its interaction with the photons, which, according to (1), represent the nuclear field. For a system S', moving with the incident photon with a velocity such that the energy of the photon is reduced from ξmc^2 to mc^2, the expression for σ thus obtained is

$$\sigma = \int_{h\nu = mc^2}^{h\nu \sim \xi mc^2} \sigma(\nu) \times (2/\pi)\, \alpha Z^2 \log (g\xi\, mc^2/h\nu)\, d\nu/\nu. \qquad (2)$$

$\sigma(\nu)$ is the cross-section for pair-production by a photon of energy $h\nu$ and a photon of energy mc^2, travelling in opposite directions. The second factor is the number of virtual photons in the nuclear field with frequency in the range $d\nu$. On substituting for $\sigma(\nu)$ the expression given by Breit and Wheeler and integrating, this gives

$$\sigma = (28/9)\, \alpha Z^2\, (e^2/mc^2)^2 \log g\xi, \qquad (3)$$

which agrees with the result obtained by Heitler and Sauter by direct application of Dirac's theory. In this formula, and also the other formulæ given in this note, g is used to denote a numerical factor of the order of unity. Its exact value in the different cases cannot be derived by the present method and this represents the degree of approximation involved.

The production of pairs in collisions between two electric particles may be deduced in a similar way, either by replacing the field of both particles by radiation and using the Breit-Wheeler formula, or only the field of one and using the Heitler-Sauter-Bethe[2] formula. Adopting the second procedure we obtain, as the cross-section for the production of a pair, of energy between εmc^2 and $(\varepsilon + d\varepsilon)mc^2$ (including energy of mass), by an electron of energy ξmc^2, in the field of a nucleus, Ze,

$$\sigma(\varepsilon)d\varepsilon = (28/9)\, \alpha Z^2\, (e^2/mc^2)^2 \log\, (0 \cdot 15\varepsilon) \times (2/\pi)\, \alpha \log\, (g\xi/\varepsilon)\, d\varepsilon/\varepsilon, \qquad (4)$$

being simply the product of the Heitler-Sauter-Bethe formula and (1) (remembering that for an electron $Z = 1$). If $\varepsilon \gg 137Z^{-1/3}$, then in the first logarithmic term in (4) we must replace $0 \cdot 15\varepsilon$ by $179Z^{-1/3}$, on account of the effect of shielding.

The cross-section for the production of a pair of any energy, according to (4), is

$$\sigma = \int_{2}^{\sim\xi} \sigma(\varepsilon)d\varepsilon = (28/27\pi)\, \alpha^2 Z^2 (e^2/mc^2)^2 (\log g\xi)^3. \qquad (5)^*$$

Regarding the pair-production by a high energy photon, it is of interest that, in the system S', to which (2) explicitly refers, the pair-production is practically all due to the interaction of photons of energy of the order of mc^2. This results from the fairly rapid convergence of the integral in (2), the integrand being asymptotically proportional to ν^{-2}. This is quite analogous to the state of affairs in the problem of radiative collisions, where the use of the Klein-Nishina scattering formula on the same lines as the present use of the Breit-Wheeler formula, shows that the emission of radiation by a high energy electron in a nuclear field may be reduced to the scattering of radiation of quantum energy[3] $\sim mc^2$. Both the pair-production formula and the radiative formula have thus a very simple theoretical basis.

A fuller discussion of the contents of this note and of other effects of charged particles which may be correlated with radiation effects will shortly be published in the *Proceedings* of the Danish Academy.

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* (4) gives only the order of magnitude of $\sigma(\varepsilon)$ if $\varepsilon \sim 1$ or $\varepsilon \sim \xi$. These regions of ε are, however, not important to the integrated cross-section. It might be remarked that (5) is in harmony with the results for pair-production by 2 particles obtained by Landau and Lifschitz by direct application of Dirac's theory, in so far as their calculations are published (NATURE, **134**, 109, July 21, 1934).

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