# Letter to the Editor

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## On the Maximal Energy Attainable in a Betatron

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BY means of a recently constructed induction accelerator-betatron, Kerst succeeded in obtaining electrons up to 20 Mev.[1] The principle of operation of the betatron is the acceleration of electrons by a tangential electric field produced by a changing magnetic flux, which is connected with the magnetic field keeping electrons on the orbit by a simple relation. In contrast to a cyclotron, whose applicability is essentially limited to the non-relativistic region on the ground of defocusing of orbits due to the change of mass at high energies, there is no such limitation for the betatron.

We may point out, however, that quite another circumstance would lead as well to the existence of a limitation for maximal energy attainable in a betatron. This is the radiation of electrons in the magnetic field. Indeed, electrons moving in a magnetic field will be accelerated and must radiate in accordance with the classical electrodynamics. One can easily see that quantum effects do not play here any important role as the dimension of the orbit is very great. As was shown by one of us[2] an electron moving in a magnetic field $\mathbf{H}$ radiates per unit of path the energy

$$-(dE/dX)=2/3(e^2/mc^2)^2(E/mc^2)^2[(\mathbf{V}/c)\mathbf{H}]^2 \qquad (1)$$

where $e$ is the charge, $m$ the mass, $\mathbf{V}$ the velocity, and $E$ the energy of the electron; $E$ is assumed much greater than $mc^2$.

In the betatron $\mathbf{V}$ is normal to $H$ and practically for the whole path equal to $c$. Then we have

$$-(dE/dX)=2/3(e^2/mc^2)^2(EH/mc^2)^2. \qquad (2)$$

The limiting value of energy $E_0$ is to be determined from the condition that the radiated energy (2) will be equal to energy gained by the electron in the electric field produced by magnetic flux per unit of path:[3]

$$\frac{2}{3}r_0^2\left(\frac{E_0H}{mc^2}\right)^2=\frac{e|d\phi/dt|}{2\pi R_0c}=\frac{e}{c}R_0|\dot{H}| \qquad (3)$$

$$\dot{H}=dH/dt \qquad r_0=e^2/mc^2.$$

Here $R_0$ is the radius of the orbit, $\phi$ is the induction flux.[1]

Hence:

$$\frac{E_0}{mc^2}=\left(\frac{3eR_0}{2r_0^2c}\frac{\dot{H}}{H^2}\right)^{\frac{1}{2}}. \qquad (4)$$

Taking for $H$ and $\dot{H}$ the values now being in use we get $E_0\approx5\times10^8$ ev, which is *only five times as great as the* energy which one expects to obtain in the betatron now under construction. From (4) one sees that $E_0$ is inversely *proportional to the magnetic field applied and proportional* to the square root of energy gained in the rotation electric field per unit of path. All this requires the using of *smaller $H$ or of higher frequencies* with the purpose of getting higher limiting values of $E_0$.

The radiative dissipation of energy of electrons moving in a magnetic field must be also of importance for the discussion of the focusing of the electronic beam, as the energy of particles being accelerated will grow more slowly with the growth of $H$ if the radiation is taken into account. This latter question may deserve a separate discussion.

[1] D. W. Kerst, Phys. Rev. 61, 93 (1942).
[2] I. Pomeranchuk, J. Phys. 2, 65 (1940).
[3] D. W. Kerst and R. Serber, Phys. Rev. 60, 53 (1941).