TABLE I. Comparison of observed and calculated resonance frequencies.

	d.c. field $H_z(Oe)$	Angular frequencies for resonance: (rad/sec.) $\times 10^{-10}$ Calculated Larmor frequencies for H_z	for $(B_zH_z)^{\frac{1}{2}}$	Experimental frequencies
Fe	2800	5.0	14.5	15.4
	500	0.9	5.8	5.9
Co	510	0.9	5.3	5.9
Ni	5000	8.8	13.5	15.4
	3800	6.7	10.9	13.2
	1030	1.8	4.9	5.9

anisotropy forces so that in the static case the spin system always points in the direction of the resultant magnetic field. In this limit the whole specimen is supposed to behave as a single domain, so that there are no complications from the domain boundaries.

We have, neglecting products of small quantities,

$$\partial M_x/\partial t=\gamma(M_yH_z+4\pi M_yM_z)=\gamma B_zM_y; \tag{2}$$

$$\partial M_y/\partial t=\gamma(M_zH_x-M_xH_z); \tag{3}$$

$$\partial M_z/\partial t\cong 0; \tag{4}$$

which gives $-\omega^2M_x=\gamma^2B_z(M_zH_x-M_xH_z)$. The susceptibility $\chi_x=M_x/H_x$ is given by

$$\chi_x=\chi_0/[1-(\omega/\omega_0)^2], \tag{5}$$

where the frequency for resonance is found to be $\omega_0=\gamma(B_zH_z)^{\frac{1}{2}}$ and is the Larmor angular frequency in the fictitious field $(B_zH_z)^{\frac{1}{2}}$. The static susceptibility χ_0 is equal to M_z/H_z and varies with the biasing field; here M_z may be taken as the saturation magnetization.

In Table I Griffiths' experimental values of ω_0 are compared with the calculated Larmor frequencies for fields H_z and $(B_zH_z)^{\frac{1}{2}}$. The gyromagnetic ratio is taken as the electron spin value. The induction B_z is calculated using 1700, 1400, and 500 as the saturation magnetization for Fe, Co, and Ni, respectively. The theory given here is seen to account quite well for the experimental results, considering that damping and anisotropy forces have been neglected.

The effect of relaxation is introduced by adding a term $-\lambda(\mathbf{M}-\chi_0\mathbf{H})$ to the right side of Eq. (1). We find

$$\frac{\chi_x}{\chi_0}=\frac{{\omega_0}^2+\lambda^2\mu_0+j\omega\lambda}{{\omega_0}^2+\lambda^2\mu_0-\omega^2+j\omega\lambda(1+\mu_0)}, \tag{6}$$

where $\mu_0=B_z/H_z$. From this it is seen that the demagnetizing field acts to increase the apparent damping.

The interpretation of a complex susceptibility in terms of the result of an electrical measurement is somewhat involved, but may be accomplished by the reasoning previously given.[2] The apparent permeability for a resistive measurement (such as a "Q" measurement) is $\mu_R=|\mu_x|(1-\sin\phi)$, where μ_x is the permeability derived from χ_x, and ϕ is the phase angle of μ_x; ϕ is always between 0 and $-\pi$.

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[1] J. H. E. Griffiths, Nature 158, 670 (1946).

[2] C. Kittel, Phys. Rev. 70, 281 (1946).

Biased Betatron in Operation

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A BIASED betatron[1-3] with closed central core has been successfully operated. The guiding magnetic field consists of a direct-current field component with a sinusoidal component superimposed, while the closed central core carries only a sinusoidal component of flux maintained at the proper magnitude by the current in a bucking coil located in grooves in the polefaces. Figure 1 shows a schematic cross section of the machine and Fig. 2 is a diagram of the principal electrical components of the energizing circuit.[1] The turn ratio of main coils to bucking coil is chosen so that the proper flux ratio and thereby the betatron 2:1 rule is fulfilled. Although radically different from previous betatrons in which the 2:1 rule was established by means of air gaps, this principle of locating the electron orbit offered no difficulties. It has the advantage of a reduction of the size of the capacitor bank since less magnetic energy storage takes place in a machine with a closed central core. The application of a direct-current bias to the main coils to produce an increased guiding field and to the bucking coil to keep the constant component out of the central flux, proved to be not critical and was tried out successfully for all ratios between main coil direct-current and crest alternating-current between 0 and 0.866. The corresponding ratio of current components in the bucking coil was always smaller for maximum x-ray output, but not critical.

No compensating or phase correcting circuits of any kind were used. Even though the a.c. components in main and bucking coils are not exactly 180 degrees out of phase,[2] theory[3] predicts that the shift of the orbit produced is very small during most of the accelerating interval and this was checked experimentally by the use of an orbit tilt circuit by means of which the electrons are made to hit a target located above the orbit.

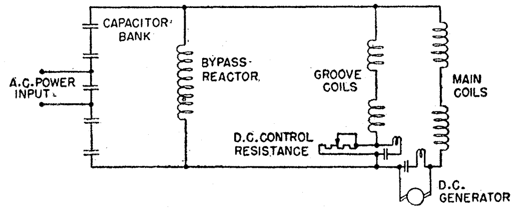

FIG. 1. Biased betatron with closed central core.

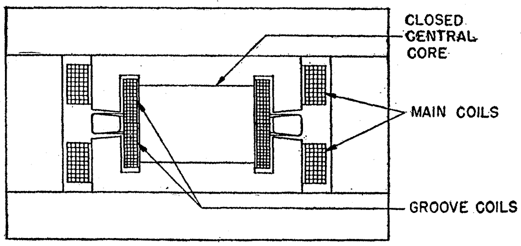

FIG. 2. Circuit diagram of biased betatron.

By means of a "megavolt meter,"[4] a direct reading of the electron energy and of the corresponding x-rays produced could be obtained in all cases. Thereby an instantaneous change from 11 Mev without d.c. bias to 20.5 Mev with d.c. bias could be produced and read by merely turning on the direct current and rephasing the electron injection pulse. In both cases, electron injection voltages as low as 8000 volts could be used indicating a high degree of uniformity of the magnetic guiding field with azimuth. With oil-cooled coils, the machine will produce 50-million volt x-rays.

[1] W. F. Westendorp, J. App. Phys. **16**, 657 (1945).
[2] Donald W. Kerst, Phys. Rev. **68**, 233 (1945).
[3] E. Amaldi and B. Ferretti, Rev. Sci. Inst. **17**, 389 (1946).
[4] W. F. Westendorp, Rev. Sci. Inst. **17**, 215 (1946).

The Capture Cross Section of Boron for Neutrons of Energies from 0.01 ev to 1000 ev*

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THE slow neutron capture cross section of boron has been measured for neutron energies from 0.01 ev to 1000 ev. The cross section was obtained by determining the transmission of boron-containing samples. Neutron energies were determined by using the method of modulation of a cyclotron beam to obtain the time of flight of the neutrons over a 7.6-meter path between the neutron moderator and a BF_3 neutron detector. This method is similar to that described by Baker and Bacher[5] and by Bacher, Baker, and McDaniel.[6] The equipment used was constructed in the Physics Department at Cornell University by B. D. McDaniel and C. P. Baker; a description will appear in the literature shortly. Neutron pulses in twelve time-of-flight intervals could be recorded simultaneously.

In order to cover the range of neutron energies four samples, each of different boron content, were used. The one containing least boron was a BF_3 gas cell; the others were B_4C. Of the three B_4C samples the thickest and thinnest consisted of cells containing B_4C powder; the third was composed of a mixture of B_4C and lead borate which was hot-pressed to form a compact disk.

The curve of total cross section σ_T *vs.* time-of-flight τ for each absorber was found to vary in the following manner

$$\sigma_T = \alpha\tau + \beta,$$

where α and β are constants. It was assumed that the constant β corresponded to the scattering cross section of the various elements present, and the term $\alpha\tau$ corresponded to the absorption cross section of boron. The scattering cross section, β, was obtained by taking the extrapolated value of σ at $\tau=0$. The scattering cross section for boron was found by correcting β for the cross sections of the other elements present. Values used were for fluorine, 4.1×10^{-24} cm², for carbon, 4.85×10^{-24} cm², for oxygen, 4.2×10^{-24} cm², and for lead 9.6×10^{-24} cm². The value obtained for the boron scattering cross section was 4.2×10^{-24} cm². The total contribution of the other elements in the B_4C samples was 2.2×10^{-24} cm² per B atom. The capture cross section of boron was obtained from

$$\sigma_a = \sigma_T - \beta = \alpha\tau$$

by assuming that all the capture cross section was represented by $\alpha\tau$ and none was included in β. In Fig. 1 the values of the product of the capture cross section by neutron velocity are plotted as a function of neutron energy. The instrumental resolution function is triangular. The resolution used depended on the energy region under investigation; in Fig. 1 the base of the triangle is equal in length to the separation of the points.

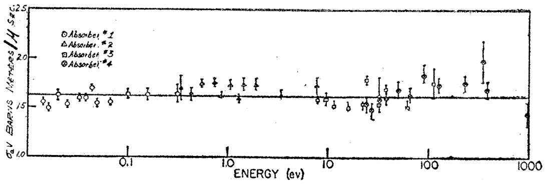

FIG. 1. The product ($\sigma_a v$) between boron absorption cross section and neutron velocity plotted against the logarithm of the neutron energy.

The value of $\sigma_a v$ determined from the weighted average of the points on the curve is $1.61\pm.02\times10^{-24}$ cm² meter/μ sec. It can be seen from the curve that systematic deviations occur between different absorbers. This is probably owing to errors in the determination of the boron content of the absorbers. The value of $\sigma_a v$ determined from the BF_3 gas alone is 1.58×10^{-24} cm² meter/μ sec. which may be a better value than the one given above, since the boron content of the BF_3 was probably better known. Both these values are lower than the figure of $118\times10^{-24}E^{-\frac{1}{2}}$ cm² (or 1.63×10^{-24} cm² meter/μ sec.) recently given by Rainwater and Havens,[7] but are higher than the value of 1.55×10^{-24} cm² meter/μ sec. obtained by Bacher, Baker and McDaniel.[6] All agree within the uncertainties given. The figure also indicates that $\sigma_a v$ is essentially constant (to ±10 percent) up to 1000 ev, if the assumption is correct that β contains only components of scattering cross section.

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[4] Now at Harvard University, Cambridge, Massachusetts.
[5] C. P. Baker and R. F. Bacher, Phys. Rev. **59**, 332 (1941).
[6] R. F. Bacher, C. P. Baker, and B. D. McDaniel, Phys. Rev. **69**, 443 (1946).
[7] J. Rainwater and W. W. Havens, Jr., Phys. Rev. **70**, 136 (1946).

Remarks on Dr. Bhabha's Note "On the Expansibility of Solutions in Powers of the Interaction Constants"

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January 13, 1947

IN a recent note Bhabha[1] has pointed out that the difference between the physical and the non-physical solutions in the classical electron theory proposed by Dirac[2] may be characterized by the fact that the former is