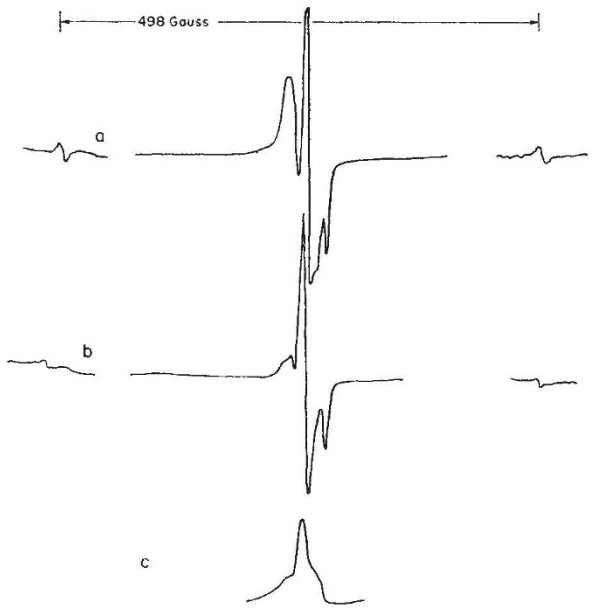

Fig. 1. Electron magnetic resonance spectrum in X-irradiated tooth at room temperature. *a*, First-derivative of the absorption immediately after irradiation; *b*, first-derivative of the absorption 2·5 days after irradiation; *c*, absorption curve corresponding to the central portion of *b* obtained by electronic integration. Spectrometer gain was reduced by a factor of 10 in the central portions of *a* and *b*

magnitude and even greater have often been measured for trapped hydrogen atoms in a solid matrix[4].

The small width and symmetric shape for the doublet lines indicate that both the *g*-value and electron-nuclear hyperfine interaction are isotropic. This fact also agrees with previous observations of hydrogen atoms in solids. Conceivable molecular defects containing one hydrogen atom would have considerable anisotropy in both *g*-value and hyperfine coupling and would also show a much smaller doublet separation.

Any phosphorus-containing defect in which the phosphorus nucleus is located at a point of less than tetrahedral symmetry would likewise possess *g* and hyperfine anisotropy[5]. Phosphorus located at a defect of tetrahedral symmetry, as in phosphorus-doped silicon, would have isotropic hyperfine coupling of only 20–30 gauss[6]. Atomic phosphorus likewise has a hyperfine splitting of 20 gauss[7].

Production of hydrogen atoms by radiation damage at low temperatures in several materials is well established. The unusual aspect of this work is that hydrogen atoms have been produced and are relatively stable at room temperature in teeth. The number of hydrogen atoms produced in the 1 mm³ sample with 10-min irradiation is about 10^{15} atoms. For the stronger unidentified species about 10^{18} defects are produced.

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A Fast-neutron Source for Radiotherapy

It would be a pity if recent correspondence[1,2] were to give the impression that 14-MeV neutrons are known to be valueless for radiotherapy on account of their low linear energy transfer. To my knowledge no measurements of the oxygen enhancement ratio of mammalian cells irradiated by 14-MeV neutrons have yet been published. An estimate of the value of this irradiation in treating tumours containing anoxic foci is therefore a matter of speculation.

In considering the effective linear energy transfer of 14-MeV neutrons, account must be taken of all the ways in which energy can be deposited in tissue. At low energies nearly all the energy is deposited by recoil protons (94 per cent at 0·3 MeV[3]). As the neutron energy rises the proportion of energy deposited by recoil protons becomes less, owing to the falling cross-section for this process, and is only 70 per cent at 14 MeV[4]. Randolph[4] made calculations at this energy allowing for the other interactions which can occur, and found a significant contribution from α-particles (mainly from the reaction $^{16}O(n,\alpha)^{13}C$). These α-particles presumably have a high relative biological effectiveness and so are biologically more effective than recoil protons. An estimate of the radiobiological effect based on the linear energy transfer of recoil protons only is therefore likely to be a poor approximation.

It is not at present possible to make a reliable estimate of the biological effects of these α-particles. However, there is a general picture that, as the linear energy transfer rises, the relative biological effectiveness of mammalian cells rises to a maximum around 50 keV/μ and then falls again[5], while oxygen enhancement ratios fall steadily[6]. The important parameter for therapy is the 'gain factor' defined by Alper[7]. A gain factor of about 1·7 has been found for cyclotron-produced neutrons having a mean energy of 6 MeV[8]. The gain factor for 14-MeV neutrons can only be estimated roughly, as the necessary radiobiological evidence is lacking. It is likely to be less than 1·7, and a calculation assuming plausible values for the radiobiological properties of the components of 14-MeV neutron radiation (recoil protons and nuclei and α-particles) suggests it may be in the region of 1·5, which would still be of therapeutic value.

Fowler[2] points out that the optimum neutron energy is likely to be a compromise between low energies giving high linear energy transfer but poor penetration, and high energies giving lower linear energy transfer but better penetration. This implies that the optimum depends on the depth of the tumour treated. It is quite possible that 14 MeV may turn out to be a suitable neutron energy for treating deep-seated lesions. On the other hand, the difficulties of collimating the beam may be greater than seem to be imagined by Lomer and Greene[9].

While the value of a source of 14-MeV neutrons for therapy remains in doubt, the construction of a more powerful source than is at present available should be welcomed as an aid to radiobiological research.

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