ABSORPTION OF MICROWAVES BY MICROORGANISMS

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RECENTLY S. J. W. and Dodds reported that 136 GHz microwaves interfere with the growth of *Escherichia coli* cells[1]. Here we report further investigations of the absorption of 65 to 75 GHz microwaves by cells of *E. coli* B_R as well as isolated protein, RNA and DNA, and its effect on some metabolic processes. Our equipment has been described[1,2]. Cells were grown for 24 h at 37° C in nutrient broth (NB) and either (*a*) washed twice in 0·85 per cent NaCl and deposited as a pellet by centrifugation or (*b*) resuspended after washing to a cell concentration of 1×10^6 cells/ml. in 0·5 per cent glucose + 0·5 per cent casamino-acids + 50 μg/ml. thymine in 0·1 M phosphate buffer, *p*H 6·9 (GCT). To examine the effect of microwaves on cell growth, 0·5 ml. aliquots of cells suspended in GCT were placed in vials 1·5 cm in diameter. Some vials were put on top of microwave horns and others incubated at the same temperature (25° C) out of the radiation field. At various times the vials were removed and the number of cells/ml. determined by dilution and plating on nutrient agar. The effect of microwave absorption on metabolic processes was investigated by resuspending the washed cells to a concentration of 1×10^8 cells/ml. in 1·0 per cent glucose in 0·1 M phosphate buffer, *p*H 6·9. Aliquots of 0·2 ml. of this suspension were placed in the vials and after positioning on the microwave apparatus 0·3 ml. of a solution was added, which contained 0·8 μCi/ml. of one of the following: thymine-2-^{14}C, uracil-2-^{14}C or algal ^{14}C protein hydrolysate plus two of the following: unlabelled thymine, 50 μg/ml.; uracil, 100 μg/ml.; or casamino-acids, 500 μg/ml. After various times the cells from each vial were deposited onto a Millipore filter and washed with 100 ml. of 1 N HCl; the filter was dried and radioactivity counted. The microwave absorption spectra of the cells, H_2O, protein, RNA and DNA were obtained by making films of the material on a thin mica window. The films were dried at 80 per cent relative humidity and covered with a second thin piece of mica. The difference between the microwave absorption of a blank and the film gave the absorption spectrum of the film of cells or biological material.

Fig. 1 shows the absorption of microwaves by cells of *E. coli* B_R as well as by H_2O, protein, RNA and DNA. The water film showed three absorption maxima at 69, 71·5 and 73·7 GHz whereas with the film of cells attenuation peaks occurred at 66, 68, 71 and 73 GHz. Absorption maxima for protein were observed at 67, 70, 71·5 and

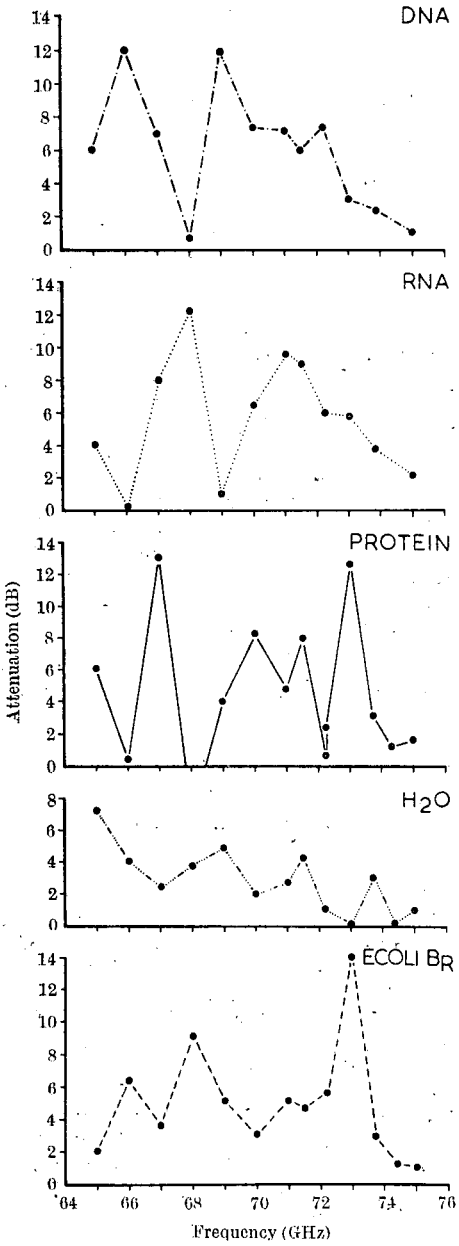

Fig. 1. The 64 to 75 GHz microwave absorption spectra of biological entities.

73 GHz with 67 and 73 GHz microwaves most strongly absorbed. Two frequencies, 66 and 69 GHz, were absorbed equally strongly by DNA and two, 68 and 71 GHz, by RNA; the former frequency was more strongly absorbed than the latter. Both RNA and DNA absorbed frequencies between 70 and 74 GHz although the strength with which they did so varied considerably. A comparison of the spectra of cells, protein, RNA and DNA showed that the absorption maxima of the cells at 66, 68 and 73 GHz corresponded to those of DNA, RNA and protein respectively. In addition, the strength of the attenuation by cells at these three frequencies was roughly equal to the relative proportions of the three types of macromolecules in the intact cell. The absorption maxima at 67 and 69 GHz, however, seen with films of protein and DNA respectively, did not occur in the spectrum of the cells. Apparently the molecular or group rotational energy levels responsible for absorption of these two frequencies by isolated material do not exist in the intact cell. This may be because of the formation of macromolecular complexes between protein and DNA in the intact cell. The same phenomenon seems to be true of the absorption at 71·5 GHz by protein and RNA. Both types of isolated macromolecules strongly absorbed this frequency yet the cells showed only a weak attenuation (Fig. 1).

Three frequencies, 66, 71 and 73 GHz, were found to slow the growth of cells whereas 68 GHz microwaves stimulated it. Two of the frequencies able to slow cell growth matched the absorption maxima of DNA at 66 GHz and of protein at 73 GHz, while the third, 71 GHz, corresponded to one of the peaks in the absorption spectrum of RNA and a shoulder in that of DNA. The frequency which seemed to stimulate growth matched one of the absorption maxima of RNA at 68 GHz. All of the frequencies which had maximal effect on growth rate corresponded with absorption peaks in the spectrum of the cells (Fig. 2).

A frequency of 66 GHz retarded both thymine and amino-acid uptake by the cells, and because protein did not absorb this frequency it seems that the absorption of 66 GHz microwaves affects a mechanism of protein syntheses dependent on concomitant or previous DNA syntheses. A frequency of 71 GHz greatly reduced the uptake of all the labelled metabolites while 71·5 GHz microwaves weakly inhibited the incorporation of thymine and amino-acids. These three frequencies also retard cell growth. Cell uptake of uracil ^{14}C was stimulated and the incorporation of amino-acids slightly enhanced by 68 GHz microwaves. This frequency stimulated cell proliferation although it had no effect on thymine uptake (Fig. 2).

Bacterial cells clearly absorb microwaves of definite frequencies and the absorbed energy alters metabolic processes and cell growth. Temperature changes do not

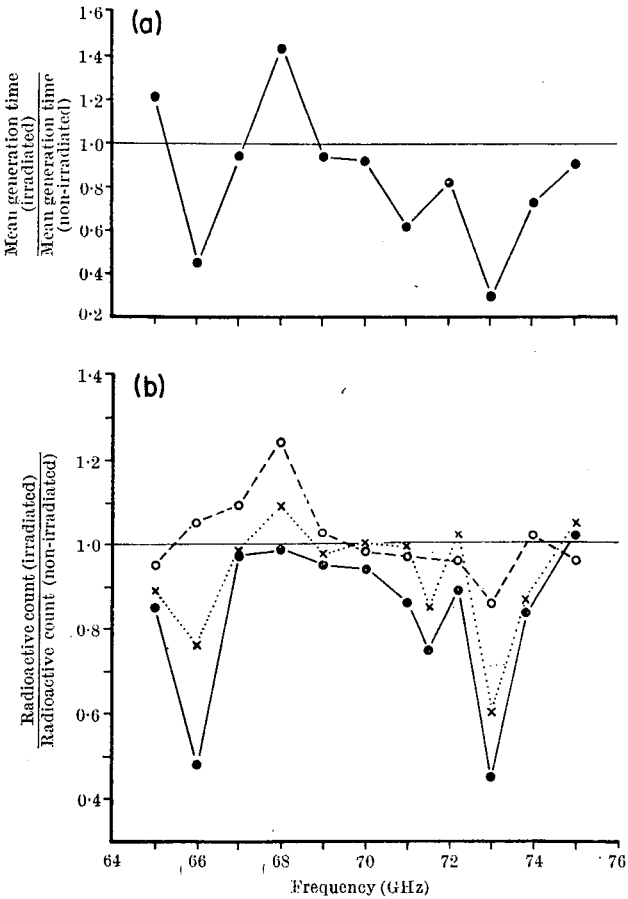

Fig. 2. The effect of various microwave frequencies on (*a*) the growth rate of *Escherichia coli* B_R and (*b*) the uptake of ^{14}C labelled metabolites. ○ - - - ○, Uracil-2-^{14}C; ●—●, thymine-2-^{14}C; × . . . ×, ^{14}C protein hydrolysate.

seem to play a part in these phenomena because, first, only a fraction of a degree rise was recorded during the experimental period, and second, the optimum growth temperature of *E. coli* is at 37° C; therefore, any increase above 25° C should have resulted in increased cell growth or metabolism, not decreases as we observed. Moreover, the cell counts showed that none of the frequencies killed the cells. While the infrared (IR) spectra of different microbes vary in small detail the differences seem to be too small for them to have practical value in cell identification. The use of mm microwaves may enable spectral differences to be enlarged. For example, the IR spectra

of DNA and RNA show only minor differences[3–6] yet their spectra between 64 and 75 GHz are clearly very different and both differ extensively from that of protein. Apart from a possible value in cell identification microwaves may prove useful in studies of *in vivo* macromolecular complexes and cell metabolism.

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