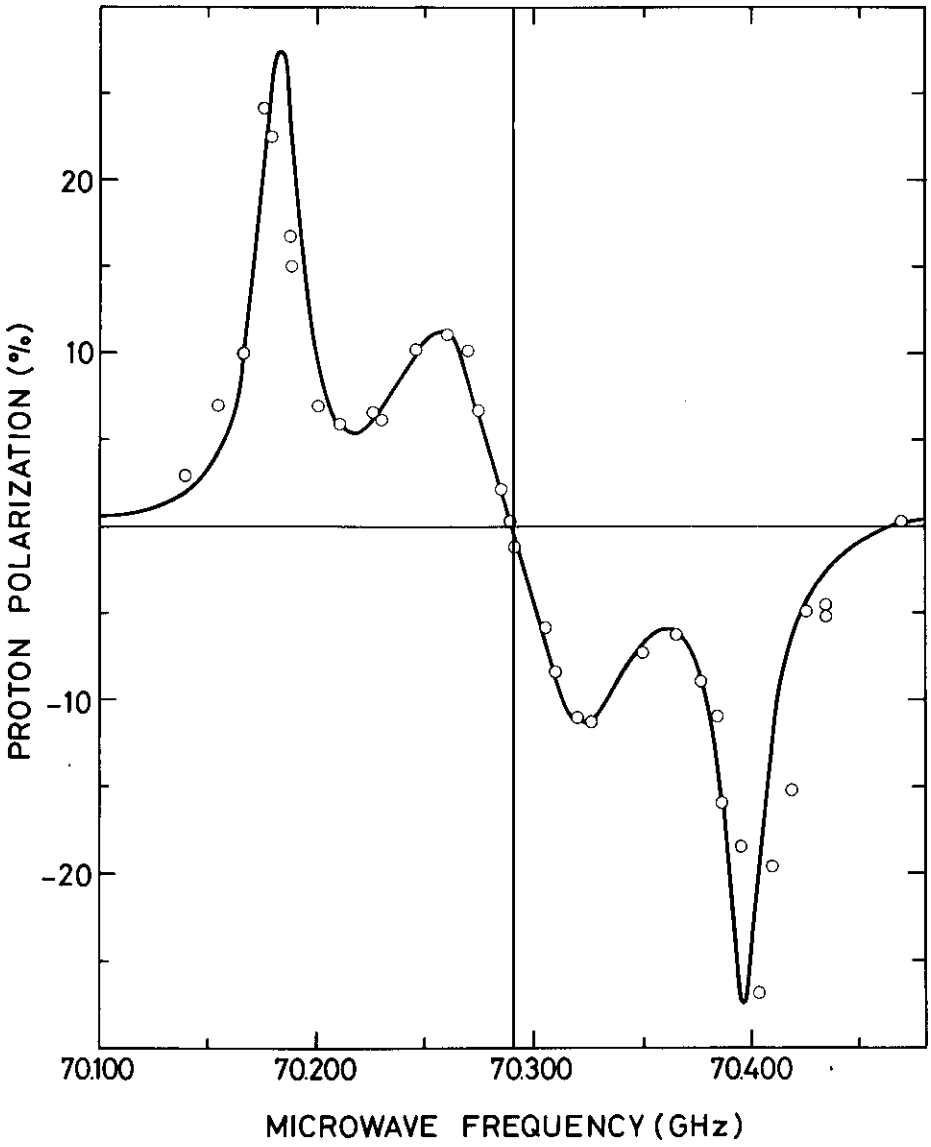

Measurement of the polarization of the protons in relation to the microwave frequency. The two high peaks on the outside may be attributed to the solid effect, while the two inside ones are due to dynamic polarization by the cooling of the electron spin-spin interaction reservoir. The theoretical curve was calculated taking both mechanisms into account. The points correspond to the experimental values.

Polarized targets

An account was given on pages 183-184 in the June, 1973, issue of the interesting results obtained with polarized proton and deuteron targets by the use of a different method of dynamic polarization based on cooling what is referred to as 'the electron spin-spin interaction reservoir'.

Since then, the mechanism of this polarization has been more thoroughly investigated, and we now know a lot more about the process.

If nuclei having a magnetic moment are placed in a uniform magnetic field, they become distributed over energy levels corresponding to the various orientations of their angular moments or spins.

In the simple case of the electron or proton, which behaves in a similar way to a small magnetized rod, there are two possible energy levels depending on the upward or downward direction of the spin.

The spins tend to assume the direction corresponding to the lowest energy state but, because of thermal agitation which, at high temperatures, is enough to cause them to break ranks, the various energy levels will all more or less be occupied to the same extent.

If, now, a sample is cooled and the thermal agitation is reduced, one can expect that the degree of polarization reached will be the higher, the more intense is the magnetic field and the lower the temperature.

With magnetic fields of 2.5 T and temperatures lower than 1 K, the free electrons of a sample are nearly all polarized. The same cannot be said of the protons, the magnetic moment of which is about three orders of magnitude lower than that of the electron; it applies still less to the deuteron, the magnetic moment of which is six times lower than that of the proton.

The solid effect method of dynamic polarization used since 1958 consists in reversing the direction of the powerful magnet formed by the electron, hoping that this magnet, which is a thousand times stronger than that of the proton, may take with it the little magnet represented by one of the protons in its vicinity.

In order to induce these 'flip-flop' transitions, the material containing the protons to be polarized is subjected to microwave irradiation, the frequency of which is selected according to the energy state to which the protons are to be taken; i.e. to have either a positive or a negative polarization.

After a flip-flop transition, the proton remains oriented in the same direction for several seconds, whereas the electron, which has been taken to its highest energy state, returns to its state of equilibrium within a period of the order of a millisecond, and is once more ready to induce fresh transitions. The free protons of a sample can, by this mechanism, be taken to high degree of polarization.

This simple explanation, taking into account only the coupling between an electron and a proton, has been found inadequate to account for the behaviour of all the very many electrons and free protons in a sample.

It has therefore been necessary to provide a quantum statistical interpretation of the polarization mechanism. This interpretation, which was studied especially by groups of the Moscow Radio-electronics Institute, the University of Leyden, Netherlands, and the CERN polarized target group, has been confirmed by a large number of experimental results.

Not all the magnets constituted by the electrons of a sample can be regarded as mutually independent, and all are capable of interacting among themselves. They have therefore come

As is covered in our main article, the CERN site is 20 years old this month. When the first people moved in, they were housed in 'temporary' barracks. How temporary can you get? The picture shows one of these barracks being dismantled a few weeks ago after twenty years of continuous use.

to be regarded as forming a group dubbed the electron spin-spin interaction reservoir, with a single parameter typifying it: the spin temperature.

The various other kinds of magnets present in the sample then form as many other energy reservoirs as there are different kinds (proton, deuteron, etc., reservoirs).

As the electron reservoir is made up of very powerful magnets in comparison with the other groups, a strong thermal coupling may be expected between the electron reservoir and each of the others. The tendency will therefore be for this thermal coupling to bring the various nuclei to the same spin temperature as the electron reservoir.

This thermal coupling provides a new dynamic polarization mechanism. If the electron spin-spin interaction reservoir can be cooled, i.e. if its spin temperature can be lowered, the spin temperature of the other reservoirs will be lowered at the same time. The direct effect of this will be to raise the polarization .of the free nuclei in the sample.

The cooling is produced by irradiating the sample with microwaves at a frequency close to the magnetic resonant frequency of the electron.

It has been possible very accurately to check this latter method experimentally, especially with partially deuterized 1.2 ethanediol (see vol. 13, page 184), in which the protons and deuterons assume the same spin temperature as the electrons, giving high polarization.

However, the two polarization mechanisms described above are closely related and difficult to distinguish. Nevertheless, the results obtained with a sample of partially deuterized m-xylene (2.2-D6) doped with BDPA (6×10^{18} spins/cm^3) proved the existence of these two mechanisms.

The results of measuring the proton polarization in relation to the microwave wavelength exhibit four peaks (see illustration), the two highest of which are caused by the solid-effect dynamic polarization mechanism, while the two lowest are due to the cooling of the electron spin-spin interaction reservoir.

The latter mechanism becomes dominant in certain substances like butanol and propanediol, for example.

Just as it is possible to produce dynamic polarization by cooling the electron spin-spin interaction reservoir, the proton interaction reservoir can be cooled by irradiation with an r.f. field. There seems to be a thermal coupling between this reservoir and the quadrupole energy reservoir of the deuterons due to the interaction with the electric field gradient in the target.

The deuterons can be purely aligned by cooling this reservoir. The alignment, like the polarization, defines a certain degree of orientation of the spins of the deuterons, which can assume three different orientations in a magnetic field. The degree of alignment may become as high as 60 % for the deuterons having a favourable orientation in the external magnetic field, and this corresponds to a spin temperature of 7 *[iK.* The average alignment of all the deuterons is unfortunately only about 10%.

Better results could probably be obtained in monocrystals, in which it is possible to select the orientation of the molecules.

BEBC dismembered

Since the beginning of March, somewhat drastic surgery has been performed on BEBC, the 3.7 m European bubble chamber.

It will be remembered that BEBC had been from time to time behaving rather oddly during the charging and discharging of the magnet. While the

