Rutherford Laboratory

Technical Leaflet

A29

POLARIZED PROTON TARGET

The interaction between a beam of protons or mesons and a target of stationary protons depends not only on the line of approach of the particles, but also on the angles of the spin axes (if any) of the bombarding particles and the spin axes of the target protons.

In most scattering experiments, the spins axes of the particles both in the incident beam and in the target are randomly orientated so that the overall scattering observed is an average over all spin directions. Much more information could be gained if all the particles in target or beam (or both) were orientated in a specific direction, i.e. were 'polarized'.

In some cases it is possible to produce a polarized beam of particles; for example a polarized proton source has been made for the P.L.A. In the equipment described here the protons in the target are polarized parallel to a strong magnetic field. (The π^- mesons to be used in the first experiment with this target have zero spin in any case.)

The protons behave like small permanent magnets, the north south direction being along the spin axis. Hence, they tend to line up like compass needles along any magnetic field in which they are placed. However, the magnetic moment of the proton is very small (they are very weak magnets), so that even when a very strong magnet field (e.g. 20,000 gauss) is used in an attempt to pull the protons into alignment, the slight vibrations which occur constantly in all materials above absolute zero of temperature are sufficient quickly to knock most of them into a random orientation with respect to the field unless the temperature is very low indeed ($\sim 1/1000^{\circ}K$).

Such temperatures are difficult to reach and virtually impossible to maintain for long periods in the face of incident energy from all sides (including the beam). Hence it is necessary to resort to a trick.

The trick consists of adding to the target (which must be made of a suitable hydrogen containing substance) a small amount of paramagnetic material, i.e. virtually to add some 'free' electrons. These electrons have a much larger magnetic moment than the protons, and so are much more easily aligned by the field. The electrons then couple magnetically to the protons and align them also. Thus at about $1\frac{1}{4}^{\circ}K$ it is possible to line up 60-80% of the electrons, and therefore of the protons, in a magnetic field of 20,000 gauss. This is the method of dynamic polarization, and was first proposed by Abragam.

Actually, the process of polarization is rather more complicated than the simple picture given above would indicate. A more detailed description follows.

The target protons are those in the water of crystallization of a single crystal of lanthanum magnesium nitrate in which 1% of the lanthanum has been replaced by neodynium. The latter, which is paramagnetic in the ionic form, provides the required free electron spins.

The crystal, as well as being immersed in a strong magnetic field at a low temperature, is also bombarded with radio waves of very short wavelength (4 mm) at exactly the right frequency to force the electron and proton magnets to reverse direction simultaneously. To escape from this forced oscillation, the electron and adjacent protons quickly relax to another state which is out of tune with the radio frequency but in which all the protons are pointing in the same direction along the magnetic field. This process may be understood better by referring to the first figure, which shows the energy levels for a coupled electron-proton pair in a magnetic field. A general arrangement of all the equipment is given in the second figure. The third figure shows the cryostat in detail, including the position of the target crystal and the nuclear magnetic resonance (NMR) coil used to measure the degree to which the protons are polarised.

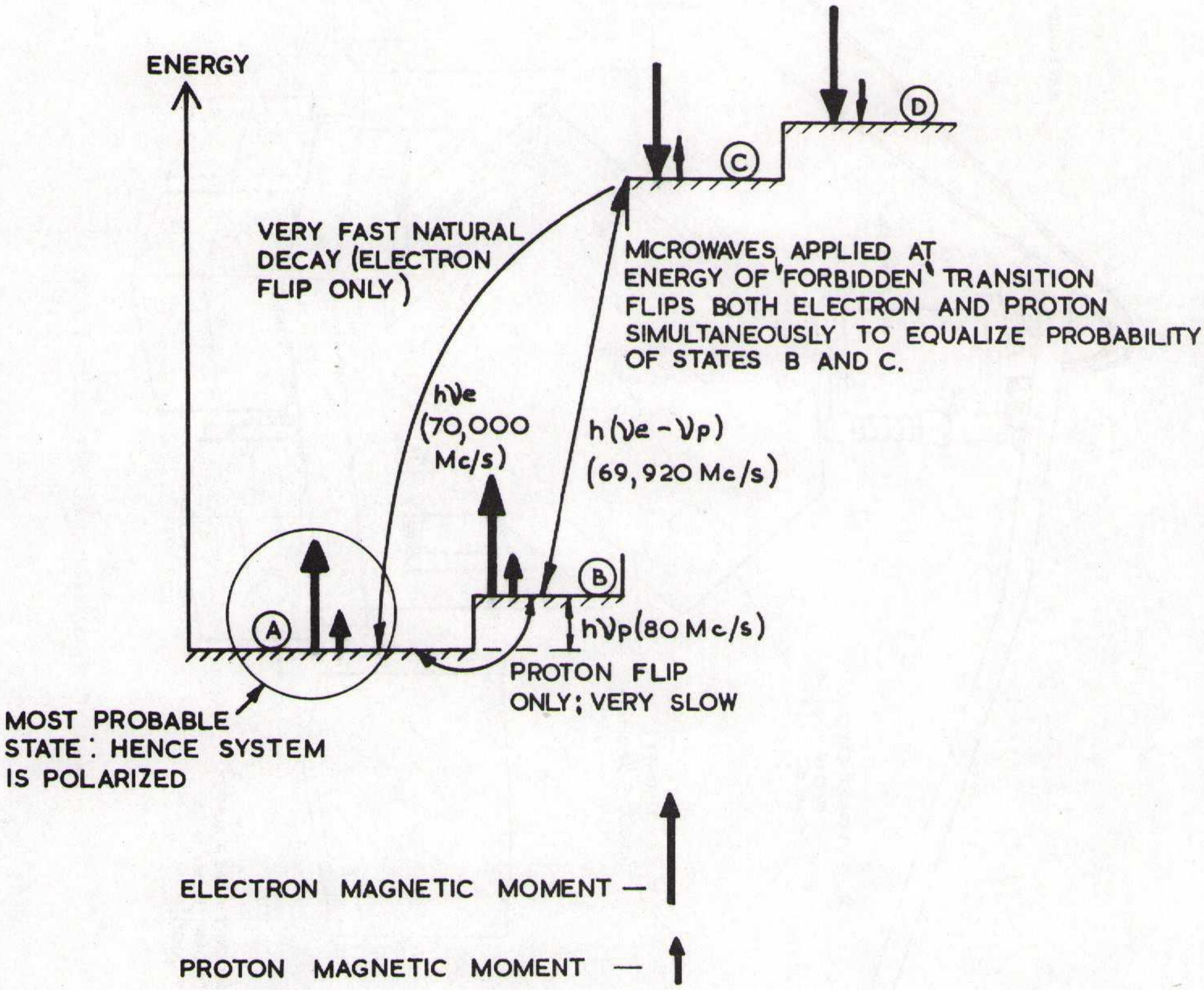

FIGURE 1. DIAGRAM OF THE FOUR POSSIBLE ENERGY LEVELS OF AN ELECTRON - PROTON PAIR.

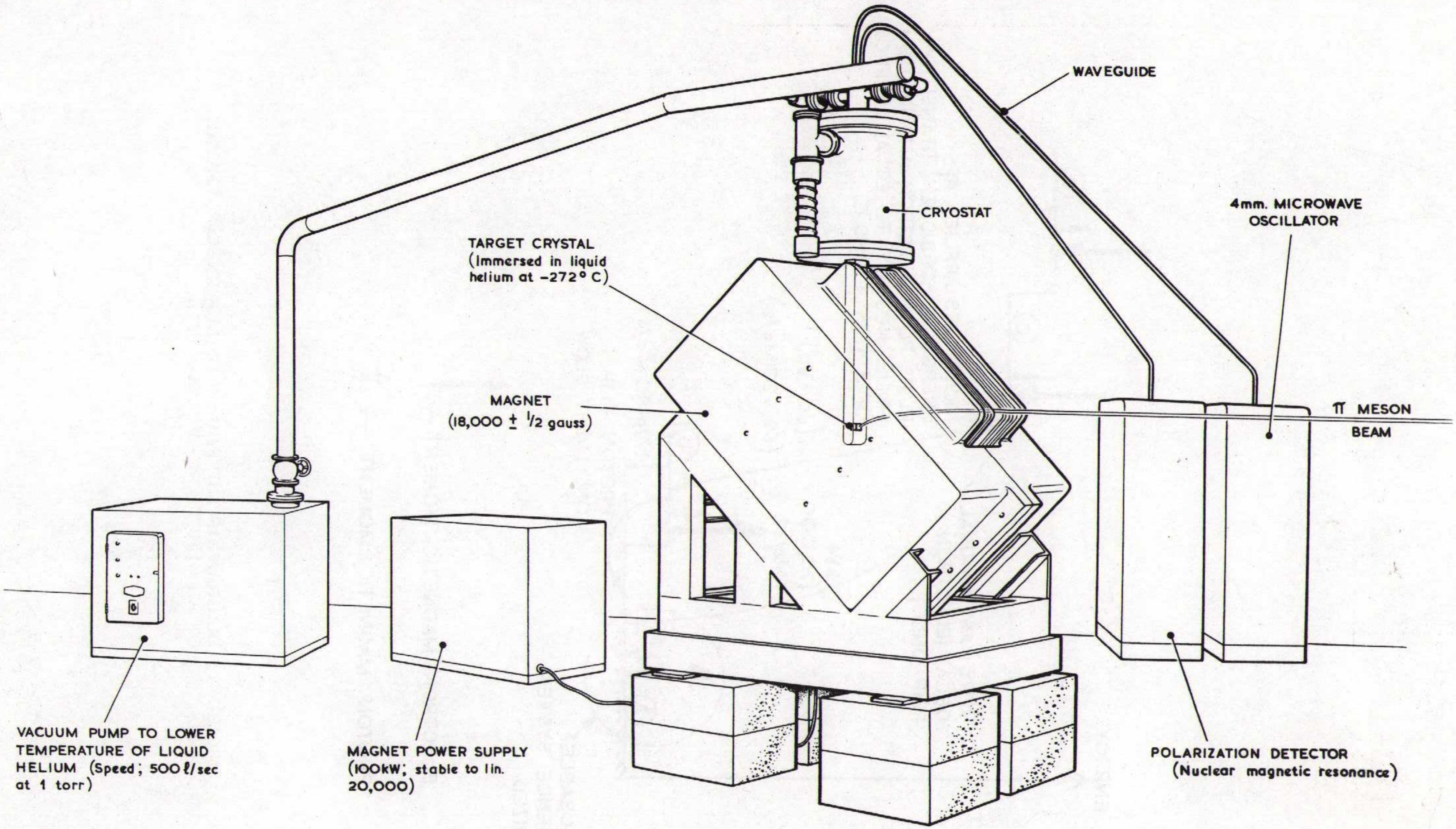

FIGURE 2. GENERAL ARRANGEMENT OF POLARIZED TARGET

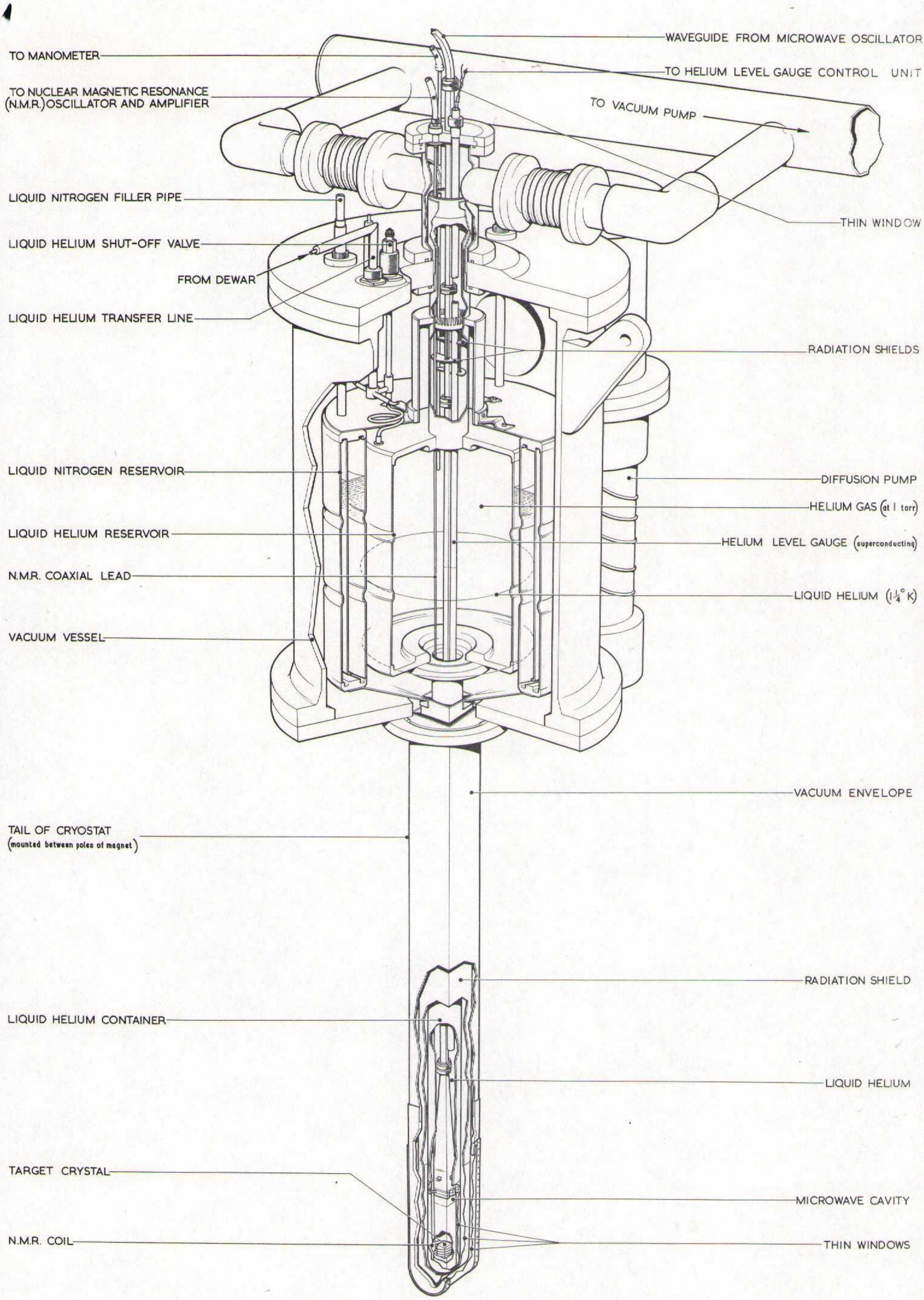

FIGURE 3. DETAILS OF CRYOSTAT