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# INELASTIC NEUTRON SPECTROSCOPY ON ISIS

## * WHAT IS INELASTIC NEUTRON SPECTROSCOPY?

Neutron spectroscopy is a technique for measuring the atomic vibrations in solids, liquids, or dense gases. The low energy slow neutrons which are produced by ISIS are shone onto the material under investigation. Neutrons are scattered by the atomic nucleus and, in certain special cases, also from the electrons surrounding the nucleus. After scattering from the sample a detector registers the neutrons and measures any change in their flight direction and their velocity. When the neutrons do not change their speed after interacting with the sample we call the scattering **elastic**, when they do change their speed we say they are scattered **inelastically**. This experimental technique, known as inelastic neutron spectroscopy, provides unique information about the motion of atoms and molecules on a nanosecond timescale.

## * WHICH MATERIALS DO WE STUDY WITH INELASTIC NEUTRON SCATTERING?

At ISIS we are studying solids and liquids in which the atoms are held together by interatomic forces like springs. These forces can be very different depending on the type of material. Solids exist in a wide variety of forms, such as metals, the new high temperature superconductors, semiconductors, organic chemicals, cement and minerals, polymers, glasses and also biological materials. It is the business of inelastic neutron scattering to measure the vibrational behaviour of the atoms in the solid and to relate this to the properties of the solids themselves.

## * WHICH ATOMIC MOTIONS MAKE THE NEUTRON CHANGE ITS SPEED IN A SCATTERING PROCESS?

### ** LATTICE VIBRATIONS

In a solid the atoms are not motionless as we might imagine but oscillate constantly around their equilibrium positions. Think of the forces between the atoms like little springs joining them together, some softer others harder. If one atom moves it will pull its neighbours in the same direction, rather like a group of happy beerdrinkers sitting on a bench and rocking together to the tune of some music. Such a concerted motion is called a lattice vibration or a phonon (so-called because it resembles a sound wave). The properties of the neutron are such that it can initiate such a motion by its impact on the sample and in doing so it loses some of its speed. Measuring the change in speed of the neutron provides a precise determination of the strength of the forces between the atoms. These motions are known as coherent vibrations.

**** SPIN WAVES**

Another opportunity for an inelastic scattering process arises because, in magnetic samples, each of the atoms has a magnetic moment, just like a small compass needle. We all recall that opposite magnetic poles attract each other whereas like poles repel. In addition to the lattice vibrations or phonons in a solid there are now also magnetic vibrations caused by the magnetic forces between the atoms. The neutron itself also carries a small magnetic moment and is therefore very sensitive to the microscopic magnetic environment in a solid and can provide detailed information on the magnetic interactions in such samples unattainable by any other methods.

**** MOLECULAR VIBRATIONS**

Up to now we have assumed that the building blocks of a solid are just simply atoms. However, there are many systems where the elementary building blocks are more complex, being molecules consisting of several and sometimes many hundreds of different atoms. In these solids we can observe additional 'internal' vibrations of the molecule itself such as the bending and stretching of bonds, or the rotations of molecular groups. The scattering from such a material is very rich in detail, comprising fundamental vibrations and many harmonics of the individual atoms within the molecule. Solids under study range from simple chemicals such as frozen methane or sodium bicarbonate to complex biochemicals such as RNA and haemoglobin.

**** DIFFUSION**

In certain materials atoms hop from site to site rather like pieces on a chess board or molecular groups click round like ratchets. The essence of these motions is their randomness and they are detected by neutrons as a broadening of the elastic scattering known as Doppler broadening. Such motions can be detected in polymers, biological materials, and even in everyday substances such as ammonium sulphate (a common garden fertilizer) or the liquid crystals used in wrist watch displays.