Dark Matter direct detection

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Abstract

There are now enough pieces of (gravitational or cosmological) evidence for the existence of dark matter in the universe. The dark matter is an unknown matter that do not emit any electromagnetic radiation and perhaps have very feeble interaction with other particles. It is now established from the study of anisotropies in apparently smooth cosmic microwave background radiation that about 26.5% of the content of the universe is made up of dark matter as compared to only a paltry amount of about 4.5% of known matter.

Although the evidence of dark matter is so far gravitational by and large, there are now worldwide endeavours to detect the dark matter directly in the laboratories. The direct detection of dark matter is based on measuring the recoil energy of the nucleus that scatters off a possible dark matter particle that may happen to interact with a nucleus of the detecting material. In order to detect such a small recoil energy, one needs to set the experiment at a very low temperature environment and a low treshold detector is called for. The principle that is employed is that the small energy deposition by the recoil nucleus at the detector increases its temperature. At a low temperature the heat capacity that follows Debye T^3 law will be negligibly small and any small deposition of energy can then be probed by the tiny rise of temperature that it may cause.

The energy of a recoil nucleus in a dark matter direct detection experiment is detected mainly via three processes namely phonons, ionisation and scintillation that the scattered nucleus may undergo inside the detecting material. The choice of the target nucleus is also important (for effective coherent scattering and scattering cross-sections). In addition, the detector should be of very high resolution. The precision measurement is required as the statistics will be low and huge background would be present. One of the principal background hazards in a dark matter direct detection experiment is the neutron background. A dark matter scattering event in a direct dark matter detection experiment can be mimicked by a neutron scattering event. Therefore proper care has to be taken to reduce the neutron background to be minimum. Also for a recoil energy $\sim$ 100 keV one principal background could be electromagnetic in nature. These originate from α particles, electrons and photons from the surrounding radioactive isotopes that may be present in the detector material. But the gamma rays can be discriminated as the deposited energy by gamma can be different from the nuclear recoil.

The process of direct detection of dark matter also depends on other astrophysics properties that should be manifested in the nature of yields. These are the annual variation of dark matter direct detection signals, the directional and daily variation of direct detection etc. These are induced by the earth's heliocentric motion (over a year) and rotational motion whereby the earth encounters the dark matter flux in different amount in different time of the year.

One other important factor in direct dark matter experiment is the coherence of elastic scattering between the dark matter particle and the target nucleus. The target becomes insensitive if the coherence is lost. One can show that the coherence is lost when the recoil energy $E_R > \frac{2\times10^4}{A^{5/3}}$ keV (A being the mass number of the target nucleus). Again, the spin independent scattering cross-section can be calulated to be $\sigma_{\rm scalar} \sim A^2$ which indicates

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that heavier the nucleus is better is the possibility that a dark matter particle will scatter to produce an event. Thus both of these phenomena are to be considered in choosing a proper material for direct dark matter experiment.

Based on the precess of detection the dark matter direct detection detectors are broadly of the types

- Scintillator Detector such as DAMA (at Gran Sasso; detector material NaI). Liquid argon or Xenon can also be used.
- Ionisation Detectors such as CoGent (at Soudan; detector material Ge crystals).
- Phonon detectors – Generally cryogenic detectors that operate at a very low temperature. CDMS at Soudan or superCDMS at SNOLAB are examples of such detectors where Ge is used as detecting material.
- Threshold detectors where the detector material is trigerred by energy dump (insensitive to electron recoil energy dumps). These are "bubble chamber" detectors such as PICASSO (detecting material - Freon) at Sudbury.
- Noble liquids such as Xenon (LUX experiment at Sanford, XMASS at Kamioka etc.), Argon (ArDM at CERN) etc.
- Detectors that give information of the directionality of the incident dark matter by reconstructing the 3D track of the recoil (a TPC gas detector).