Cosmological Microwave Background

The fan of colours that we see when sunlight passes through a prism, or a piece of cut glass, is known as a *spectrum*. Scientifically, the different colours are different wavelengths of light and the spectrum extends beyond those colours that we can see with our eyes. The broader range of wavelengths is known as the *electromagnetic spectrum*. With special equipment we can detect *infrared waves* (as used in night vision goggles and TV remote controls), *microwaves* (as used in microwave ovens and satellite TV dishes) and *radio waves*. All these have longer wavelengths than those we can see.

At the shorter wavelength end, blue light is followed by *ultra violet* (sun beds), *X-rays* (as used in medical diagnosis) and *gamma rays* (used sometimes for treating cancer).

In 1962, Penzias and Wilson found a continual 'hiss' of microwaves that can be detected with the right equipment. This hiss does not change with time (so nothing artificial on Earth is producing it) and is virtually identical in strength in all directions (so not emanating from a localised source, such as the Sun).

The most convincing explanation for this hiss comes out of the theory behind the Big Bang. Early in cosmic history, we believe that the entire universe was filled with an extremely hot and fully ionised, dense gas (a *plasma*), which emitted and absorbed radiation at very short wavelengths (gamma rays). As the universe expanded, it also cooled[1] and once it reached an age of about 380,000 years, atoms formed, and the radiation was suddenly unable to interact with the matter to the same extent, as the number of free charges in the universe dramatically reduced.

Cosmologists say that the universe became *transparent*, although as with many things that cosmologists say they mean something technical and rather specific. They do not use the word in quite the same way that we use transparent when referring to glass. As atoms have formed, there are no longer free charges throughout the universe. Electromagnetic radiation is emitted and absorbed by charges, a process that is much less frequent when all the charges are trapped inside atoms. Rather than being scattered around, the radiation is now free to move through the universe, which is what is meant by having a transparent universe.

The radiation that was emitted by charges just before atoms formed is still present everywhere in the universe. It has been travelling in all directions. As the universe expanded, this radiation was red shifted, so that it is now in the microwave part of the spectrum. We are bathed in this radiation.

The detailed study of this radiation has become fundamentally important in the study of cosmology. It provides us with detailed information about the structure of matter in the early universe, as well as important measurements of key parameters. A detailed explanation of how this information is extracted is beyond the bounds of what we can pursue here.

[1] Normally when you talk of something cooling it happens because the heat has flowed to something else. In the case of the whole universe there is nowhere else for the heat to go. The universe cools as it expands in that the kinetic energy of its constituent particles reduces. Basically, the energy is turned into gravitational energy as the objects get further and further apart. In the case of the radiation in the universe, it 'cools' in the sense that it is red shifted to wavelengths that would be emitted by a cooler object.