The Forces of Nature

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Four fundamental forces rule the universe: gravity, the electromagnetic force and then two that act in and around the atomic nucleus, known as strong and weak. The latter pair act over distances smaller than atoms and so are less familiar to our macroscopic senses than are the effects of gravity and magnets. However, they are critical to our existence, keeping the Sun burning and providing the essential warmth for life.

The four appear very different in their strengths, characters and influences. However, it is beginning to look as if in the early moments of the Universe, immediately after the Big Bang with which everything began some 15 billion years ago, these forces were united. In the last two years there has even been a growing suspicion that all of them might actually be gravity in disguise. The bizarre idea is that there are more dimensions than our senses are aware of and that gravity is the effect of forces leaking into these new dimensions. Is this science fiction or science fact? That is the question, but one that may soon be answered.

Gravity is familiar; it rules the universe at large. Galaxies whirl, planets orbit and apples fall to earth from on high due to the attraction of gravity. When the apple hits the ground it is smashed to pulp: it is the electromagnetic force that is responsible. Electromagnetic forces grip atoms to one another building up molecules and the solidity of matter. You and I and everything are held together by the electromagnetic force. So it is gravity that pulls us to the ground and the electromagnetic force that stops us falling to the centre of the planet.

Atoms consist of negatively charged electrons whirling around a positively charged central nucleus. It is the attraction of opposite charges that grip the electrons in their orbits to form atoms, and the repulsion between like charges that helps to keep neighbouring atoms apart.

Gravity attracts matter together into spherical stars, like the Sun, and nearly spherical planets like our Earth. The Earth rotates, which makes its equator bulge, and there are mountains that also spoil the spherical perfection. How big could those mountains be? Larger than 10 km and their weight would melt the atomic bonds at their base. On neutron stars the matter is so dense, the gravity so powerful, that the biggest mountain could be no bigger than the size of an atom.

On Earth you could escape its gravity if you jumped up at a speed greater than 11 km/second. Thats out of the question for you and I but rockets can achieve such speeds and escape into outer space. On a neutron star the escape speed would be much higher. The extremes are reached with the veritable, well named, black hole. Here a star has collapsed to such density that even light cannot escape its gravity.

With such dramatic effects, you would be excused for thinking of gravity as being intrinsically a powerful force. However, this is not so. Between individual atoms or their constituent particles, the effects of gravity are nugatory. It is the fact that gravity attracts everything to everything else that make its effects add up until they are powerful, acting over cosmic distances. The electromagnetic force is intrinsically much more powerful; however, the competition between attractions and repulsions neuter its effects over large distances leaving gravity as the dominant effect at large. However, the effects of swirling electric charges in the molten core of the Earth cause magnetic fields to leak into space. A compass needle will point to the north pole, which may be thousands of miles distant, due to such effects.

The attraction of opposites holds the electrons in their atomic orbits around the positively charged nucleus, but the repulsion of like charges creates a paradox for the existence of the nucleus itself. The nucleus is compact, its positive electrical charge due to the many positively charged protons within it. But how can these protons, suffering intense electrical repulsion courtesy of their common positive charges, manage to stay put? You would think that the nuclei of atoms would explode, if they had ever managed to form at all.

This gives the clue that there is an even more powerful attractive force at work: the strong force. This force acts only within the nucleus and we now know that it is due to the presence of the quarks, the ultimate basic particles from which protons and neutrons are formed. The quarks have a new form of charge, called colour, which behaves like electric charge in that like colours repel and unlike attract. In the talk I will illustrate how this gives rise to the proton, and nuclear forces, and also how in essence it is similar to the electromagnetic force. And as the latter gives rise to electromagnetic radiation, and its agents photons, so the colour charge also gives a radiation, whose agents are known as gluons. It is these gluons that glue the quarks to one another to make protons, neutrons and atomic nuclei.

However, there are three different varieties of colour charges (either positive or negative) whereas there is only one type of electric charge. This gives rise to subtle differences between the effects of electromagnetism and the strong colour forces, e.g., electromagnetism can act over atoms and beyond whereas the colour induced forces act only over nuclear dimensions.

A tantalizing hint of unity has emerged. The behaviour of atomic particles at very high energies, akin to those that were abundant just after the Big Bang, suggests that the colour forces are enfeebled, and similar in strength to the familiar electromagnetic force. There are further hints of such a unity as I shall now describe.

The remaining force is the weak force, so called because it appears weak (by comparison to the electromagnetic and strong) at room temperatures. The weak force disrupts neutrons and protons, causing the nucleus of one element to transmute into another through the phenomenon known as radioactivity. This also is important in making the Sun shine. Gravity pulls the solar material inwards until they impinge and the weak force transmutes the solar protons into neutrons, the strong force then clumping protons and neutrons into the nuclei of helium. Energy is released and radiated courtesy of the electromagnetic force. It is the presence of these four forces and their different characters and strengths that keep the sun bunring at just the right rate for us to be here.

Yet it appears that it hasnt always been like this. At CERN we can study how these forces behave at extreme energies. We have seen that the weak force is only weak at room temperatures; at higher energies it takes on the strength and some of the character of the electromagnetic force. There is a radiation from the weak force carried by W and Z particles. Unlike the photons of light which are well, light the W and Z are heavy. Why they are and where this mass comes from is believed to be due to the Higgs Boson, still to be found and the stuff of another talk.

That much we know. Extrapolate the effects of the colour forces, and of the weak and electromagnetic to extreme energies, far beyond what we can measure in the lab, and it appears that all three become alike. This is known as grand unification of the forces. It suggests that there is an underlying simplicity, unity, to Nature and that we have only glimpsed a cold asymmetric remnant of it so far. Whether this is really true is for future experiments to test.

Now for the really bizarre. According to the latest theories the three dimensions of space and that of time are just a part of a more profound universe. There are dimensions that are beyond perception by our usual senses but which could be revealed in forthcoming high energy experiments at CERN.

To make some sense of this imagine a universe perceived by flatlanders, aware of only two dimensions. Now with our greater awareness know of a third. So we can imagine two flat plates separated by, say, a millimeter. The effects of forces on one plate could leak across the gap but the flatlanders would not realize this. They would perceive the remnant effects, which would be feeble in comparison to the effects when restricted to the plane.

Such ideas are for another lecture, but the idea is that gravity appears feeble because it is the effect of the other forces leaking out into the higher dimensions in our universe.. So when we feel gravity, we are feeling the effect of the other unified forces which have leaked away into the higher dimensions leaving a trifling remnant to do its work. One could even imagine particles moving from our flatlander dimensions into the higher dimensions and in effect disappearing from the universe as we know it. Whether this is so, and how we might find the answer will be the theme of a talk next year.

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