Cosmic Chemistry: Cosmogony

Density and Gravity: The Push and Pull of the Universe

STUDENT TEXT

DENSITY

As you read Appendix A, "Cosmology," a major issue surrounding the question of the "big bang" and the structure of the universe is the value of omega (Ω), which relates to the density of the universe. Omega is an index of matter density of the universe, defined as the ratio of actual density to the critical density. In contrast to many of the concepts of cosmology that are not part of our everyday life (black holes, for example), density is something that we deal with frequently. Statements like, "Those packing peanuts are really light" or "My books are really heavy," are not uncommon. Often, when we make these kinds of statements, we are not necessarily referring to the mass of the object, but rather to its density. Everyone understands our meaning because the concept of density is pretty fundamental. Wouldn't we all immediately agree that bricks are more dense than cotton balls? Would you rather have a brick or box of cotton balls dropped on one of your toes? Clearly, we have an intuitive feeling for the concept of density.

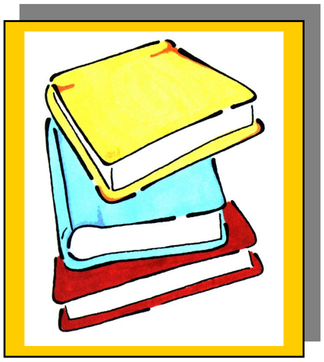
As you probably know, a precise definition of density is the ratio of an object's mass to its volume (Density = mass divided by volume). So when we say that a brick is more dense than a cotton ball, we mean that if we compare equal volumes of bricks and cotton balls, the bricks will have more mass.

It is easy to experimentally determine the density of some objects, especially those having a regular shape, such as a cube. By measuring their masses and calculating their volumes from physical measurements of their dimensions, it is a simple matter to apply the equation above and determine their density. Density is a derived quantity, meaning that it cannot be measured directly. Rather it must be derived from other measurements.

For other objects, the determination of density is not so easy. The problem usually is not the determination of the object's mass. Rather it is irregular shapes that cause the problem. In these cases, one must use a good deal of ingenuity to determine the object's volume.

The determination of the density of the universe is a very difficult problem. What is its mass? What is the volume of the universe? Clearly these values cannot be determined directly and astronomers are forced to make approximations, guesses, and simplifications.

GRAVITY



"What goes up must come down" is a common statement that all of us have heard in one context or another. Certainly when it comes to objects tossed upward from the Earth's surface by everything except the most powerful of rockets, this is a statement with which everyone would agree. And we all know that the reason that everything tossed upwards comes back to the ground is the attraction of gravity. So we all have experience with gravity—it holds our feet to the ground, it holds our atmosphere in place, it is responsible for tides, and it holds the planets in their orbits around the sun. Clearly gravity is an absolutely major force in the universe.

But what is this thing called "gravity"? Do we really understand its origin—where it comes from? Do we understand why gravity is always attractive—never a repulsive force? The answer to these and related questions is, "not really." If we examine the history of gravity, we find that the name of Sir Isaac Newton again looms large and most of our everyday ideas about gravity relate to his discoveries. For example, Newton was the first scientist to associate the orbits of the planets with gravitation. But there is more to it than this. Einstein's theory of General Relativity, dating from the early 20th century, is actually a modern theory of gravity; however, this theory is conceptually difficult (gravity is the geometry of space and time) and is couched in sophisticated mathematical terms. Consequently, we usually think of gravity in Newton's terms rather than Einstein's terms for everyday purposes.

An important conclusion from Newton's work is that the gravitational force between two objects is proportional to the inverse of their separation squared, ($F \propto 1/r^2$). Further, it is called a universal law because it applies to any two masses irrespective of their size. Clusters of galaxies, atomic particles, and human beings are all subject to gravitational forces. Also, gravity operates over all distances as far as we can tell. You are subject to the gravitational forces of distant celestial objects, although the gravitational forces of the Earth have much more influence on you personally than do those of, say, the giant planet Jupiter. It is impossible to escape from gravity.

When you walk past someone in the hallway you do not have to worry about being attracted to them gravitationally because the force is so small. Gravitational forces manifest themselves in a tangible way only when at least one of the interacting masses are large. In all of your classroom discussions of atoms, the topic of gravity was not raised. Why? Because at the atomic level the forces of gravity, while present, are so vastly overshadowed by the electromagnetic force that they do not have any recognizable presence. It is the tiny mass of the particles in the atom that makes the gravitational force small compared to the electromagnetic force.

So, the force of gravitational attraction is related to the mass of interacting objects as well as their separation. How does this figure into the equation? This is pretty easy to determine, since the magnitude of the force increases directly with masses, ($F \propto m_1m_2$).

When all of this is combined we have: $F \propto m_1m_2/r^2$. To convert the proportionality to an equality, it is necessary to insert a proportionality constant. Thus the mathematical statement of Newton's ideas becomes: $F = G\ m_1m_2/r^2$, where G is called the **Gravitational Constant** and has the value 6.67×10^{-11} $Nm^2\ Kg^{-2}$ when the m's are in kilograms and r is in meters. The force will then will be in Newtons.