Making Sense of the Universe (rest of Chapter 4 and some of Chapter 5): Momentum, Energy, and Matter

Newton's Laws of Motion can be reduced to one principle - the principle of conservation of momentum. Momentum is the product of mass and velocity. The total momentum of a group of interacting objects stays the same if no external forces are acting on them.

If something is going round and round in circles, it has angular momentum. This can be either orbital angular momentum (the object is going around a distant point, such as a planet orbiting a star) or rotational angular momentum (the object is spinning around some axis inside that object, such as a planet rotating around its axis once per day or an ice skater spinning around). The orbital angular momentum of a planet is the product of its mass, its speed, and its distance from the Sun. There is also a principle of conservation of angular momentum: The angular momentum of a set of interacting objects can only be altered by an external torque. This explains Kepler's second law and is also important for understanding solar system formation.

Energy is what makes matter move. Energy cannot be created or destroyed, only exchanged or transferred – the third big conservation principle. Energy can be kinetic energy, potential energy, or radiative energy. Kinetic energy is the energy of motion. An object's kinetic energy increases if its mass or velocity increase. The disordered motion of molecules is a form of kinetic energy called thermal energy. The molecules inside hot objects are moving faster than those inside cold objects. Potential energy is energy stored within matter in some way. The greater the mass of an object and the higher up it is, the greater its gravitational potential energy. Falling objects convert gravitational potential energy into kinetic energy as they accelerate. Mass-energy, or $E=mc^2$, is a form of potential energy. Radiative energy is light.

Atoms consist of a nucleus of protons and neutrons surrounded by a cloud of electrons. Atoms have equal number of protons and electrons. Electrons have a negative charge, protons have a positive charge, and neutrons have no charge. Particles with the same charge repel each other, particles with opposite charges attract each other. Protons and neutrons are much heavier than electrons. The number of protons in an atom specify what chemical element that atom is. Two atoms with the same number of protons, but different numbers of neutrons, are different isotopes of the same element.

An atom is much, much larger than its nucleus. Interactions between electrons in different atoms are responsible for most of the properties of atoms. The nucleus just sits at the centre of the atom and doesn't do very much. Atoms can bond together to form molecules. The molecules that make up a larger object control its chemical properties. Whether something is gas, liquid, or solid is controlled by how easily its molecules can move around each other.

Atoms store energy in electrical potential energy of their electrons. Electrons are only allowed to possess certain amounts of energy. Electron energy levels are quantized. This is very important for how light and matter interact.