8.1: Fundamental Principles of Dynamics

Roughly speaking, there have been three eras of physics, characterized by three different answers to the question of what makes things go.

Pre-Newtonian Dynamics

Aristotle expounded a view of dynamics which agrees closely with our everyday experience of the world. Objects only move when a force is exerted upon them. As soon as the force goes away, the object stops moving. The act of pushing a box across the floor illustrates this principle — the box certainly doesn't move by itself!

Newtonian Dynamics

In contrast to earthly behavior, the motions of celestial objects seem effortless. No obvious forces act to keep the planets in motion around the sun. In fact, it appears that celestial objects simply coast along at constant velocity unless something acts on them. The Newtonian view of dynamics — objects change their *velocity* rather than their position when a force is exerted on them — is expressed by *Newton's second law*:

$$\mathbf{F} = m\mathbf{a} \quad \text{(Newton's second law)}, \tag{8.1.1}$$

where **F** is the force exerted on a body, *m* is its mass, and **a** is its acceleration. *Newton's first law*, which states that an object remains at rest or in uniform motion unless a force acts on it, is actually a special case of Newton's second law which applies when **F** = 0.

It is no wonder that the first successes of Newtonian mechanics were in the celestial realm, namely in the predictions of planetary orbits. It took Newton's genius to realize that the same principles which guided the planets also applied to the earthly realm as well. In the Newtonian view, the tendency of objects to stop when we stop pushing on them is simply a consequence of frictional forces opposing the motion. Friction, which is so important on the earth, is negligible for planetary motions, which is why Newtonian dynamics is more obviously valid for celestial bodies.

Note that the principle of relativity is closely related to Newtonian physics and is incompatible with pre-Newtonian views. After all, two reference frames moving relative to each other cannot be equivalent in the pre-Newtonian view, because objects with nothing pushing on them can only come to rest in one of the two reference frames. Newton's second law obeys the principle of relativity because the acceleration of an object is the same when viewed from two different reference frames moving at a constant velocity with respect to each other.

Einstein's relativity is often viewed as a repudiation of Newton, but this is far from the truth — Newtonian physics makes the theory of relativity possible through its invention of the principle of relativity. Compared with the differences between pre-Newtonian and Newtonian dynamics, the changes needed to go from Newtonian to Einsteinian physics constitute minor tinkering.

Quantum Dynamics

In quantum mechanics, particles are represented by matter waves, with the absolute square of the wave displacement yielding the probability of finding the particle. The behavior of particles thus follows from the reflection, refraction, diffraction, and interference of the associated waves. The connection with Newtonian dynamics comes from tracing the trajectories of matter wave packets. Changes in the speed and direction of motion of these packets correspond to the accelerations of classical mechanics. When wavelengths are small compared to the natural length scale of the problem at hand, the wave packets can be made small, thus pinpointing the position of the associated particle, without generating excessive uncertainty in the particle's momentum. This is the geometrical optics limit of quantum mechanics.