Chapter 5
Applying Newton's Laws

In this chapter we will introduce further applications of Newton's 1^{st} and 2^{nd} law. In summary, all of the *contact* forces and *action-at-a-distance* forces will go on the left hand side of the Newton's equations to obtain $\sum F$. Likewise, the resultant forces will go on the *right-hand side* of the equation. During this course, we will only investigate two kinds of resultant forces, (i) constant, straight-line acceleration, and (ii) constant, centripetal acceleration due to uniform circular motion.

$$\sum F = ma \qquad \text{where} \qquad ma = ma \qquad \text{or} \qquad ma = \frac{mv^2}{R}$$

1 Using Newton's 1^{st} Law: Particles in Equilibrium

Ex. 1 Two 25.0-N weights are suspended at opposite ends of a rope that passes over a light, frictionless pulley. The pulley is attached to a chain that goes to the ceiling. a) What is the tension in the rope? b) What is the tension in the chain?

Ex. 10 In **Fig. E5.10** the weight w is 60.0 N a) What is the tension in the diagonal string? b) Find the magnitudes of the horizontal forces $\vec{F}_1$ and $\vec{F}_2$ that must be applied to hold the system in the position shown.

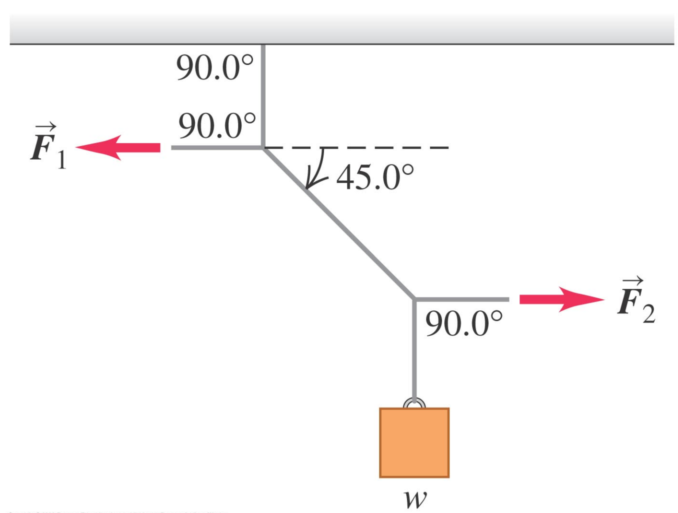

Figure 1: Figure E5.10 (University Physics)

2 Using Newton's 2^{nd} Law: Dynamics of Particles

Ex. 15 **Atwood's Machine** A 15.0 kg load of bricks hangs from one end of a rope that passes over a small, frictionless pulley. A 28.0-kg counterweight is suspended from the other end of the rope, as shown in **Fig. E5.15**. The system is released from rest. a) Draw two free-body diagrams, one for the load of bricks and one for the counterweight. b) What is the magnitude of the upward acceleration of the load of bricks? c) What is the tension in the rope while the load is moving? How does the tension compare to the weight of the load of bricks? To the weight of the counterweight?

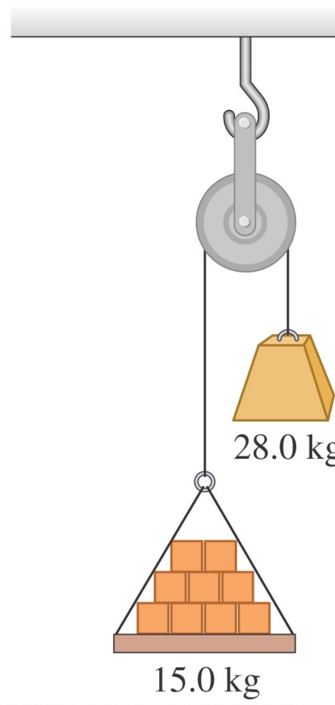

Figure 2: Figure E5.15 (University Physics)

Prob. 90 Two blocks connected by a cord passing over a small, frictionless pulley rest on frictionless planes **(Fig. 5.90)**. a) Which way will the system move when the blocks are released from rest? b) What is the acceleration of the blocks? c) What is the tension in the cord?

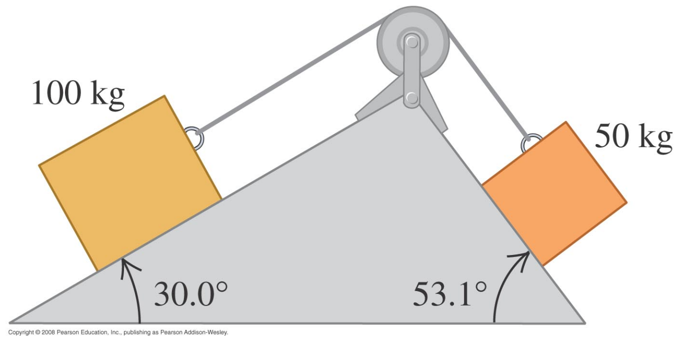

Figure 3: Figure P5.90 (University Physics)

3 Frictional Forces

Friction is a *contact* force that we often see in everyday life. There are two kinds of friction that we will study in this chapter, *kinetic* friction and *static* friction. In both cases, the friction force will depend on n the normal force.

3.1 Kinetic Friction

As the name implies, *kinetic* friction is the force between two objects *slipping* or *sliding* against each other. The magnitude of the force is written as:

$$f_{\mathrm{k}} = \mu_{\mathrm{k}}\, n$$

where μ_{k} is the coefficient of kinetic friction, and n is the normal force. **Note:** The friction force f_{k} and normal force n are perpendicular to each other.

3.2 Static Friction

Similar to kinetic friction, *static* friction depends on the normal force and is perpendicular to the normal force. Unlike *kinetic* friction, *static* friction has a range of forces extending from 0 to $(f_s)_{\text{max}}$.

$$0 \le f_s \le (f_s)_{\text{max}} \qquad \text{where} \qquad (f_s)_{\text{max}} = \mu_s\, n$$

where μ_s is the coefficient of static friction. If the external force opposing the friction exceeds the maximum static-friction force $(f_s)_{\text{max}}$, then the object begins to slide, then the rules of *kinetic friction* begin to apply.

Ex. 27 A stockroom worker pushes a box with mass 16.8 kg on a horizontal surface with a constant speed of 3.50 m/s. The coefficient of kinetic friction between the box and the surface is 0.20. a) What horizontal force must the worker apply to maintain the motion? b) If the force calculated in part (a) is removed, how far does the box slide before coming to rest?

3.3 Terminal Speed

When an object is moving through a fluid it experiences *fluid resistance.* Using Newton's 3rd law, we see that the fluid pushes back on the body with an equal and opposite force. The direction of fluid resistance ($\vec{F}_{\text{fluid resistance}}$) is always opposite to the velocity vector $\vec{v}$. The magnitude of *fluid resistance* will vary for objects moving at different velocities.

Slow Speeds: The resisting force at low speeds depends on the size and shape of the body along with the properties of the fluid.

$$f = kv$$

where k is a constant of proportionality. One example of this motion is Stoke's Law which describes the force applied to a sphere of radius r as it moves through a fluid having a viscosity η.

$$F = 6\pi\eta r v$$

Fast Speeds: The resisting force at high speeds is called "air drag" and can be written as

$$F = Dv^2$$

where D is the constant of proportionality that depnds on the shape and size of the body and on the density of the air. **Note:** the units of D are different from the units of k.

Example: How do we apply Newton's 2nd law to a rock released at the surface of a deep pond?

$$\sum F_y = mg + (-kv_y) = ma_y \qquad \text{Note: } +y \text{ direction is downward} \tag{1}$$

If the rock reaches **terminal speed** (i.e., the velocity reaches its maximum, and no longer changes), then the above equation reduces to:

$$\sum F_y = mg + (-kv_y) = 0$$

and the terminal velocity is $v_t = (mg/k)$.

However, if you want to know the velocity as a function of time $v_y(t)$ as the speed approaches *terminal velocity*, then you must solve Eq. 1 with the caveat that the resisting force, and thus, the acceleration are no longer constant in time. The book solves Eq. 1 for v_y and obtains the following:

$$v_y(t) = v_t \left(1 - e^{-(k/m)t}\right) \tag{2}$$

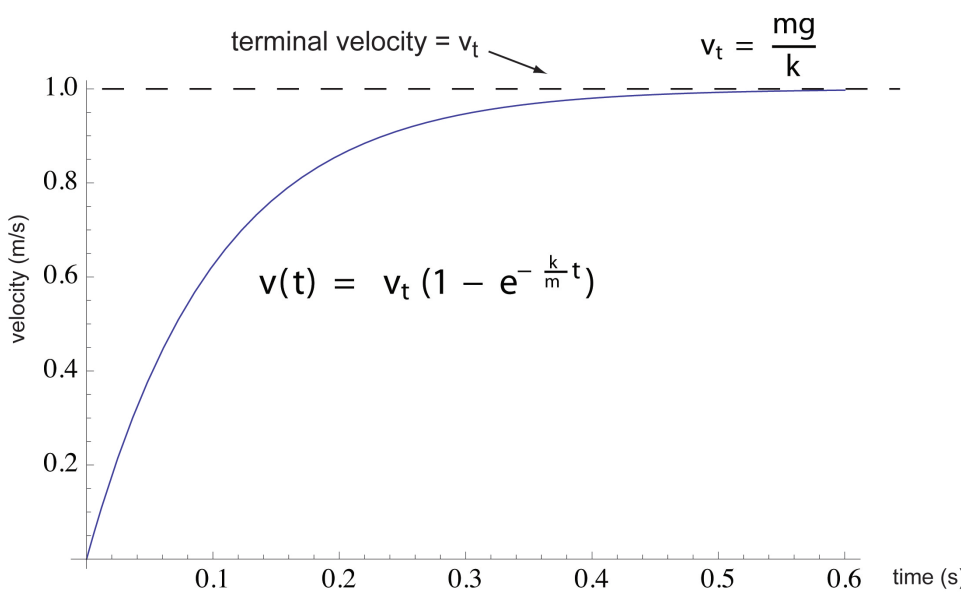

Figure 4: Velocity as a function of time for a dissipative force $F_y = -kv_y$ where $v_t = 1$ m/s.

Differentiating Eq. 2 with respect to t, we find the acceleration a_y:

$$a_y(t) = ge^{-(k/m)t} \qquad \text{(notice that } a_y \text{ is not constant)}$$

Integrating Eq. 2 with respect to t, we find the equation of motion $y(t)$:

$$y(t) = v_t \left[t - \frac{m}{k}\left(1 - e^{-(k/m)t}\right)\right]$$

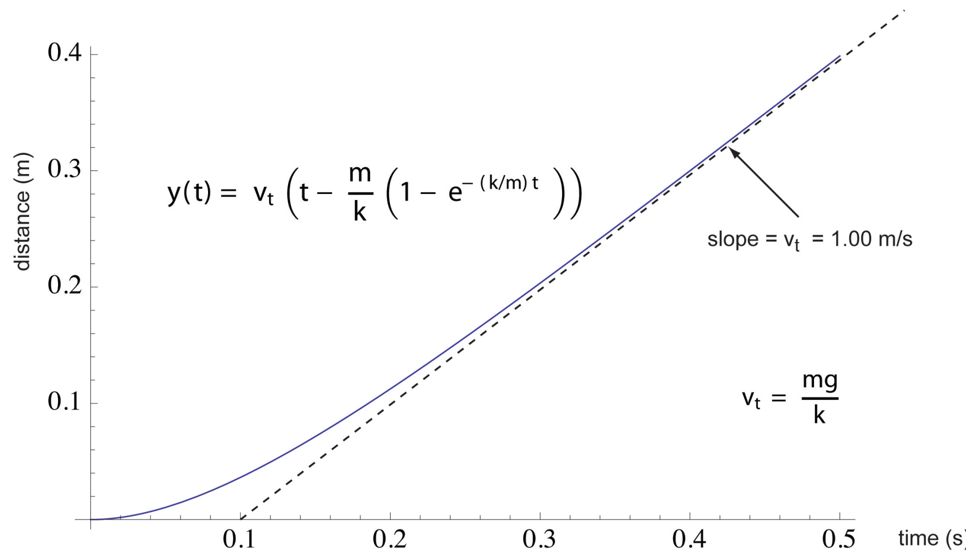

Figure 5: Distance as a function of time for a dissipative force $F_y = -kv_y$.

Ex. 40 You throw a baseball straight up. The drag force is proportional to v^2. In terms of g, what is the y-component of the ball's acceleration when its speed is half its terminal speed and a) it is moving upward? b) it is moving back down? Note: the terminal speed is $v_t = \sqrt{mg/D}$.

4 Dynamics of Circular Motion

Previous to this section, we limited the motion of particles *along a straight line.* We also assumed that the acceleration was along a straight line. In this section we investigate a "different" kind of resultant force, one that gives rise to uniform circular motion. We saw in a previous chapter that circular motion requires acceleration directed toward the center of the circular path, in particular, centripetal acceleration ($a_{\rm rad} = v^2/R$). Thus, Newton's 2$^{\rm nd}$ law takes on the following form:

$$\sum F = m\frac{v^2}{R}$$

Example: Calculate the tension in a simple pendulum of mass m and length ℓ, and angle θ.

Ex. 53 Rotating Space Stations. One problem for humans living in outer space is that they are apparently weightless. One way around this problem is to design a space station that spins about its center at a constant rate. This creates "artificial gravity" at the outside rim of the station. (a) If the diameter of the space station is 800 m, how many revolutions per minute are needed for the "artificial gravity" acceleration to be 9.80 m/s^2? (b) If the space station is a waiting area for travelers going to Mars, it might be desirable to simulate the acceleration due to gravity on the Martian surface (3.70 m/s^2). How many revolutions per minute are needed in this case?

Example: A car is traveling at 20 m/s on level ground and begins to execute a turn with a radius of curvature of 70 m. What is the *minimum* coefficient of static friction μ_s required to keep it in its circular path?

Prob. 99 Banked Curve I. A curve with a 120-m radius on a level road is banked at the correct angle for a speed of 20 m/s. If an automobile rounds this curve at 30 m/s, what is the minimum coefficient of static friction needed between the tires and the road to prevent skidding?

5 The Fundamental Forces in Nature

We presently know of four "fundamental" forces in nature. Two of them are long-range forces (gravity and electromagnetism), the other two are short-range forces (weak and strong).

Force	Range	Strength	Particle	Spin
Strong	$\sim$ 1 fm	1	gluon	1 $\hbar$
Weak	$\sim$ 1 fm	$\sim 10^{-6}$	$W^{\pm}$, Z^o	1 $\hbar$
Electromagnetic	∞	$\sim 10^{-2}$	photon	1 $\hbar$
Gravity	∞	$\sim 10^{-40}$	graviton	2 $\hbar$

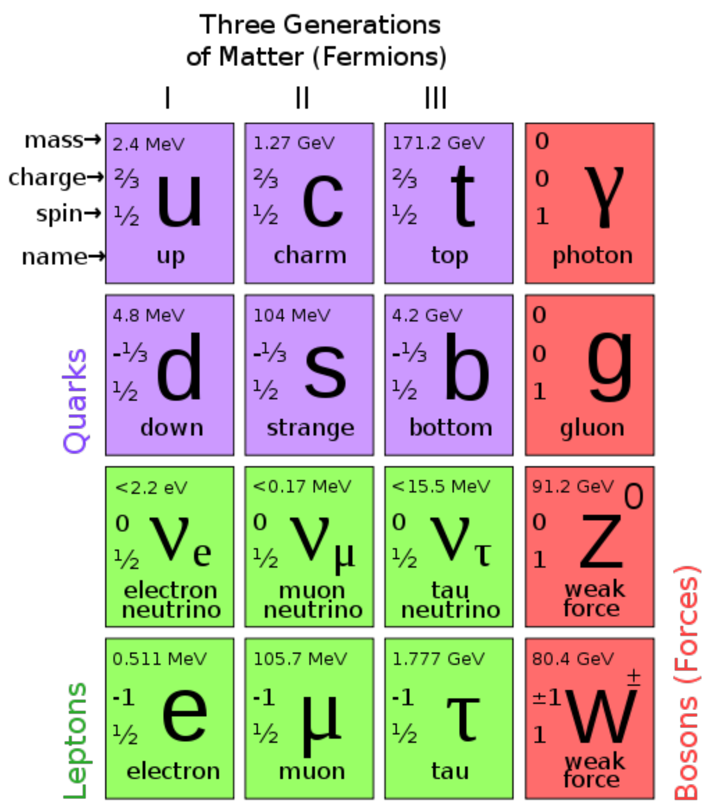

Figure 6: The Standard Model showing the force carriers for the 4 fundamental forces.

Feynman Diagrams

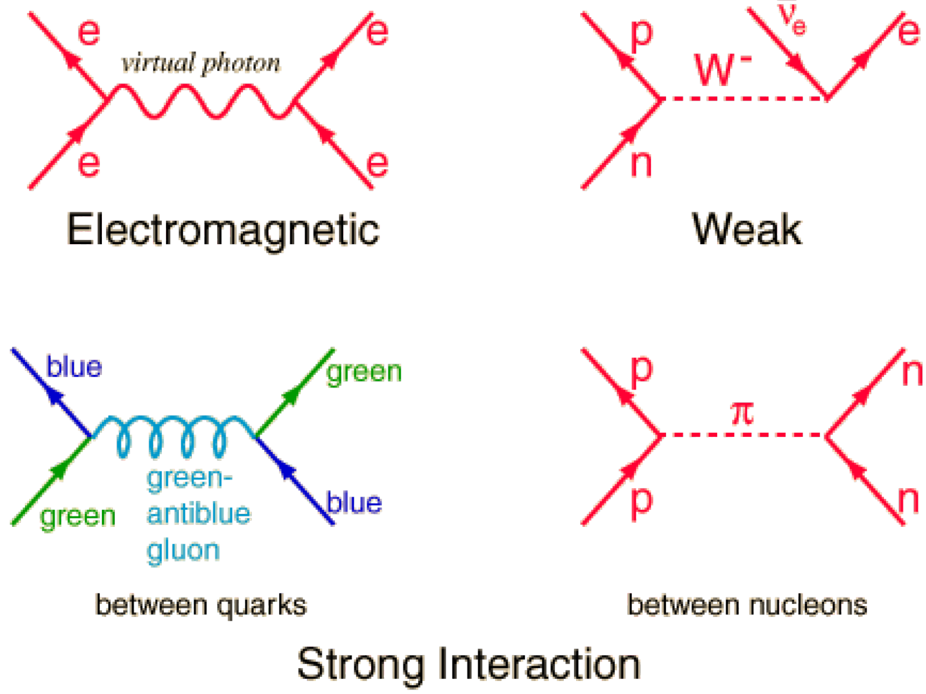

Figure 7: The exchange particles are the force carriers.