Physics 2A
Chapter 5: Applying Newton’s Laws

“You've got a lot of choices. If getting out of bed in the morning is a chore and you're not smiling on a regular basis, try another choice.” – Steven D. Woodhull

“The greater part of our happiness or misery depends on our dispositions, and not our circumstances.” – Martha Washington

Reading: pages 131 – 158

Outline:

⇒ equilibrium
    static and dynamic equilibrium
⇒ dynamics and Newton’s 2nd Law
⇒ mass and weight
    apparent weight
⇒ normal forces (read on your own)
⇒ friction
    static friction
    kinetic friction
    rolling friction
⇒ drag (read on your own)
⇒ interacting objects (read on your own)
⇒ ropes and pulleys
⇒ inclined planes

Problem Solving

A definite procedure has been devised to solve dynamics problems. It ensures that you consider only one object at a time, reminds you to include all forces on the object you are considering, and guides you in writing Newton's second law in an appropriate form. Follow it closely. Use the list below as a check list until the procedure becomes automatic.

1. Identify the object to be considered. It is usually the object on which the given forces act or about which a question is posed.

2. Represent the object by a dot on a diagram.

3. On the diagram, draw arrows to represent the forces on the object. Try to draw them in roughly the correct directions. The tail of each arrow should be at the dot. Label each arrow with an algebraic symbol to represent the magnitude of the force, regardless of whether a numerical value is given in the problem statement.

4. Draw a coordinate system on the diagram. In principle, the placement and orientation of the coordinate system do not matter as far as obtaining the correct answer is concerned but some choices reduce the work involved. If you can guess the direction of the acceleration, place one of the axes along that direction. The acceleration of an object sliding on a surface at rest, such as a table top or inclined plane, for example, is parallel to the surface. Once the coordinate system is drawn, label the angle each force makes with a coordinate axis. This will be helpful in writing down the components of the forces later.
   The diagram, with all forces shown but without the coordinate system, is called a free-body diagram. We add the coordinate system to help us carry out the next step in the solution of the problem.

5. Write Newton's second law in component form: $\sum F_x = ma_x$ and $\sum F_y = ma_y$. The left sides of these equations should contain the appropriate components of the forces you drew on your diagram. You should be able to write the equations by inspection of your diagram. Use algebraic symbols to write them, not numbers; most problems give or ask for force magnitudes so you should usually write each force component as the product of a magnitude and the sine or cosine of an appropriate angle.

6. Identify the known quantities and solve for the unknowns.

Many problems of this chapter deal with frictional forces. Proceed as before: draw a free-body diagram and write down Newton's second law in component form, just as for any other second-law problem. Use an algebraic symbol, f say, for the magnitude of the frictional force. You must now decide if the frictional force is static or kinetic (or rolling). If static friction is involved, f is probably an unknown but is related to other known quantities in the problem. Kinetic friction is involved if one surface is sliding on the other. Then, the magnitude of the frictional force is given by $\mu_k N$.

To decide on the direction of a force of static friction, first decide which way the object would move if the frictional force were absent. The frictional force is in the opposite direction. Consider an object on an inclined plane that is tilted so the object will slide down if you do not exert a force on it. Suppose, however, you pull on it with a force F that is parallel to the plane and directed up the plane. You will find that you can apply a fairly wide range of forces without having the object move. If F is small, the force of friction is up the plane; if F is large, the force of friction is down the plane. The static frictional force can have any value from $\mu_s N$ down the plane to $\mu_s N$ up the plane (including 0), depending on the value of F.

In some situations the surface of contact is moving. Consider, for example, a crate on the bed of a moving pick-up truck. If the crate and truck move together, the force of friction acting on the crate is whatever is necessary to give the crate the same acceleration as the truck. This must be less than $\mu_s N$, where N is the normal force of the truck on the crate. If the static frictional force that is required to hold the crate on the truck is greater than $\mu_s \mathrm{N}$, then the crate slides and the magnitude of the frictional force is given by $\mu_k N$.

SUMMARY

The goal of Chapter 5 has been to learn how to solve problems about motion in a straight line.

GENERAL STRATEGY

All examples in this chapter follow a three-part strategy. You'll become a better problem solver if you adhere to it as you do the homework problems. The *Dynamics Worksheets* in the *Student Workbook* will help you structure your work in this way.

Equilibrium Problems

Object at rest or moving at constant velocity.

PREPARE Make simplifying assumptions.

- Check that the object is either at rest or moving with constant velocity ($\vec{a} = \vec{0}$).
- Identify forces and show them on a free-body diagram.

SOLVE Use Newton's second law in component form:

$$\sum F_x = ma_x = 0$$

$$\sum F_y = ma_y = 0$$

"Read" the components from the free-body diagram.

ASSESS Is your result reasonable?

Dynamics Problems

Object accelerating.

PREPARE Make simplifying assumptions. Make a **visual overview:**

- Sketch a pictorial representation.
- Identify known quantities and what the problem is trying to find.
- Identify all forces and show them on a free-body diagram.

SOLVE Use Newton's second law in component form:

$$\sum F_x = ma_x \text{ and } \sum F_y = ma_y$$

"Read" the components of the vectors from the free-body diagram. If needed, use kinematics to find positions and velocities.

ASSESS Is your result reasonable?

Objects in Contact

Two or more objects interacting.

PREPARE Make a **visual overview:**

- Sketch a pictorial representation.
- Identify all forces acting on *each* object.
- Identify action/reaction pairs of forces acting on objects in the system.
- Draw a *separate* free-body diagram for each object.

SOLVE Write Newton's second law for each object. Use Newton's third law to equate the magnitudes of action/reaction pairs. Determine how the accelerations of the objects are related to each other.

ASSESS Is your result reasonable?

IMPORTANT CONCEPTS

Specific information about three important forces:

Weight $\vec{w} = (mg, \text{downward})$

Friction $\vec{f}_s = (0 \text{ to } \mu_s n, \text{direction as necessary to prevent motion})$

$\vec{f}_k = (\mu_k n, \text{direction opposite the motion})$

$\vec{f}_r = (\mu_r n, \text{direction opposite the motion})$

Drag $\vec{D} \approx (\frac{1}{4}\rho A v^2, \text{direction opposite the motion})$ for motion in air

Newton's laws are vector expressions. You must write them out by **components:**

$$(F_{\text{net}})_x = \sum F_x = ma_x$$

$$(F_{\text{net}})_y = \sum F_y = ma_y$$

For equilibrium problems, $a_x = 0$ and $a_y = 0$.

APPLICATIONS

Apparent weight is the magnitude of the contact force supporting an object. It is what a scale would read, and it is your sensation of weight:

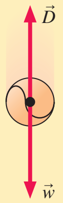
$$w_{\text{app}} = m(g + a_y)$$

Apparent weight equals your true weight $w = mg$ only when $a_y = 0$.

A falling object reaches **terminal speed**

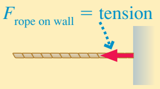
$$v_{\text{term}} \approx \sqrt{\frac{4mg}{\rho A}}$$

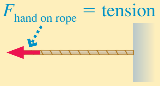
Terminal speed is reached when the drag force exactly balances the weight force: $\vec{a} = \vec{0}$.



Strings and pulleys

- A string or rope pulls what it's connected to with a force equal to its tension.
- The tension in a rope is equal to the force pulling on the rope.
- The tension in a massless rope is the same at all points in the rope.
- Tension does not change when a rope passes over a massless, frictionless pulley.



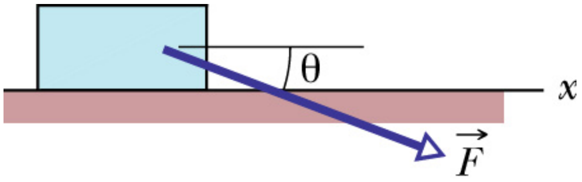


Questions and Example Problems from Chapter 5

Question 1
A ball is thrown straight up. Taking the drag force of air into account, does it take longer for the ball to travel to the top of its motion or for it to fall back down again.

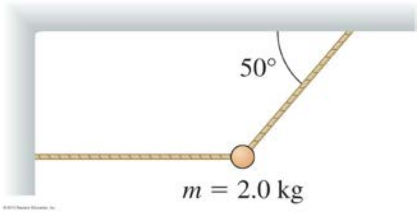
Question 2
If you press an apple crate against a wall so hard that the crate cannot slide down the wall, what is the direction of (a) the static frictional force $\vec{f}_s$ on the crate from the wall and (b) the normal force $\vec{N}$ on the crate from the wall? If you increase your push, what happens to (c) f_s, (d) N, and (e) $f_{s,max}$?

Question 3
In the figure below, if the box is stationary and the angle θ of force $\vec{F}$ is increased, do the following quantities increase, decrease, or remain the same: (a) F_x; (b) f_s; (c) N; (d) $f_{s,max}$? (e) If, instead, the box is sliding and θ is increased, does the magnitude of the frictional force on the box increase, decrease, or remain the same?



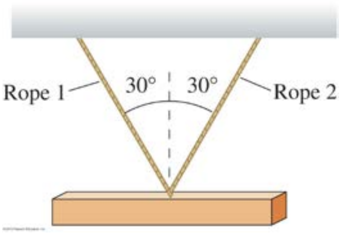
Problem 1

A 2.0 kg ball is suspended by two light strings as shown in the figure below. What is the tension in each string?



Problem 2

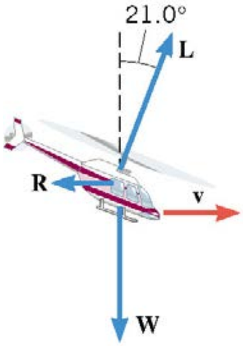
A 1000 kg steel beam is supported by the ropes shown in the figure below. Each rope can support a maximum sustained tension of 5600 N. Do the ropes break?



Problem 3

The helicopter in the drawing is moving horizontally to the right at a constant velocity. The weight of the helicopter is 53,800 N. The lift force **L** generated by the rotating blade makes an angle of 21.0^{o} with respect to the vertical. (a) What is the magnitude of the lift force?

(b) Determine the magnitude of the air resistance **R** that opposes the motion.



Problem 4

A rock of mass 45 kg accidentally breaks loose from the edge of a cliff and falls straight down. The magnitude of the air resistance that opposes its downward motion is 250 N. What is the magnitude of the acceleration of the rock?

Problem 5

A 95.0 kg person stands on a scale in an elevator. What is the apparent weight when the elevator is (a) accelerating upward with an acceleration of 1.80 m/s^2, (b) moving upward at a constant speed, and (c) accelerating downward with an acceleration of 1.40 m/s^2?

Problem 6

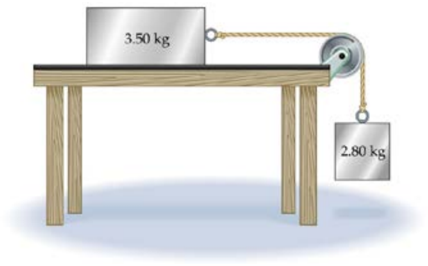
A 1000 kg car is traveling at a speed of 40 m/s skids to a halt on wet concrete where $\mu_k = 0.60$. How long are the skid marks?

Problem 7
A block whose weight is 45.0 N rests on a horizontal table. A horizontal force of 36.0 N is applied to the block. The coefficients of static and kinetic friction are 0.650 and 0.420, respectively. Will the block move under the influence of the force, and, if so, what will be the block’s acceleration? Explain your reasoning.

Problem 8
A 70.0 kg crate is dragged across a floor by pulling on a rope with a force of 500.0 N at an angle of 15.0° above the horizontal. If $\mu_k = 0.35$, what is the acceleration of the crate?

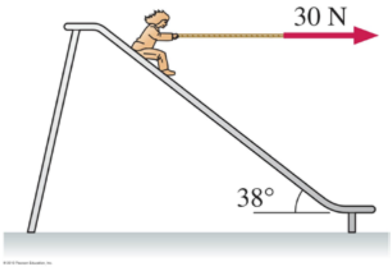
Problem 9

A 3.50 kg block on a frictionless tabletop is attached by a string to a hanging block of mass 2.8 kg, as shown in the figure below. The blocks are released from rest and allowed to move freely. (a) Is the tension in the string greater than, less than, or equal to the weight of the hanging mass? (b) Find the acceleration of the blocks and the tension in the string.



Problem 10

A 23 kg child goes down a straight slide inclined 38° above the horizontal. The child is acted on by his weight, the normal force from the slide, kinetic friction, and a horizontal rope exerting a 30 N force as shown in the figure below. How large is the normal force of the slide on the child?



Problem 11

A box is sliding up an incline that makes an angle of 15.0° with respect to the horizontal. The coefficient of kinetic friction between the box and the surface of the incline is 0.180. The initial speed of the box at the bottom of the incline is 1.50 m/s. How far does the box travel along the incline before coming to rest?