Physics 4A
Chapter 5: Force and Motion and
Chapter 6: Dynamics I: Motion Along a Line

"The answers you receive depend upon the questions you ask." – Thomas Kuhn

"*Life is a mirror and will reflect back to the thinker what he thinks into it.****"*** – Ernest Holmes

Reading: pages 110 – 126; 131 – 152

Outline:

Chapter 5

⇒ introduction to forces (PowerPoint)
⇒ a short catalog of forces
    gravity, spring force, tension, normal force, friction
    drag, thrust, electric and magnetic forces
⇒ free-body diagrams
⇒ Newton's First Law
⇒ Newton's Second Law

Chapter 6

⇒ mechanical equilibrium
⇒ using Newton's Second Law
⇒ mass, weight, and gravity
⇒ friction
    static, kinetic, and rolling
⇒ drag (read on your own)
⇒ more examples of Newton's Second Law
    inclined planes
    example problems

Problem Solving

A definite procedure has been devised to solve Newton's laws 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 or by a sketch of its outline. Do not include the environment of the object since this is replaced by the forces it exerts on the object.

3. On the diagram, draw arrows to represent the forces of the environment on the object. Try to draw them in roughly the correct directions. The tail of each arrow should be at the dot or outline. 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.

   The hard part is getting all the forces. If appropriate, don't forget to include the gravitational force on the object, the normal force of a surface on the object, and the forces of any strings or rods attached to the object. Carefully go over the sample problems in the text to see how to handle these forces.

   Some students erroneously include forces that are not acting on the object. For each force you include you should be able to point to something in the environment that is exerting the force. This simple procedure should prevent you from erroneously including a normal force, for example, when the object you are considering is not in contact with a surface.

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: $F_{\text{net}\,x} = ma_x$, $F_{\text{net}\,y} = ma_y$, and, if necessary, $F_{\text{net}\,z} = ma_z$. 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. If more than one object is important, as when two objects are connected by a string, you can sometimes treat them as a single object. To do this you must know that their accelerations are the same. On the other hand, if you are asked for the force of one object on another, you must carry out the steps given above separately for each object. There is then an additional condition you must consider. Usually the condition is that the magnitudes of their accelerations are the same. You must then invoke Newton's third law: the force of the two objects on each other are equal in magnitude and opposite in direction. Use the same algebraic symbol to represent the magnitudes of these forces and draw their arrows in opposite directions on the free-body diagrams.

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

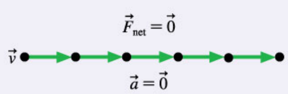
Many problems from Chapter 6 deal with frictional forces. Proceed as before: draw a free-body diagram and write down Newton's second law in component form, just as for any other second-law problem. Use an algebraic symbol, f say, for the magnitude of the frictional force. You must now decide if the frictional force is static or kinetic. If static friction is involved, f is probably an unknown but the acceleration is known or is related to other known quantities in the problem. If the object is at rest on a stationary surface, for example, its acceleration is zero. If it is at rest relative to an accelerating surface, its acceleration is the same as that of the surface. 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.

GENERAL PRINCIPLES

Newton's First Law

An object at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force on the object is zero.



The first law tells us that no "cause" is needed for motion. Uniform motion is the "natural state" of an object.

Newton's laws are valid only in inertial reference frames.

Newton's Zeroth Law

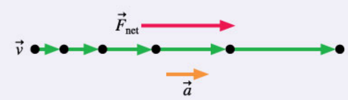
An object responds only to forces acting on it *at this instant*.

Newton's Second Law

An object with mass m has acceleration

$$\vec{a} = \frac{1}{m}\vec{F}_{net}$$

where $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$ is the vector sum of all the individual forces acting on the object.



The second law tells us that a net force causes an object to accelerate. This is the connection between force and motion.

IMPORTANT CONCEPTS

Acceleration is the link to kinematics.

From $\vec{F}_{net}$, find $\vec{a}$.

From a, find v and x.

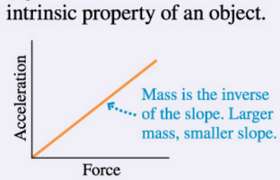
$\vec{a} = \vec{0}$ is the condition for **equilibrium**.

An object **at rest** is in equilibrium.

So is an object with **constant velocity**.

Equilibrium occurs if and only if $\vec{F}_{net} = \vec{0}$.

Mass is the resistance of an object to acceleration. It is an intrinsic property of an object.



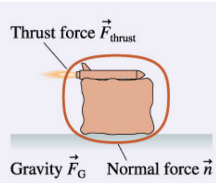
Force is a push or a pull on an object.

- Force is a vector, with a magnitude and a direction.
- Force requires an agent.
- Force is either a contact force or a long-range force.

KEY SKILLS

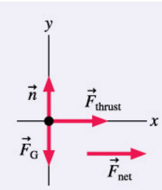
Identifying Forces

Forces are identified by locating the points where other objects touch the object of interest. These are points where contact forces are exerted. In addition, objects with mass feel a long-range gravitational force.



Free-Body Diagrams

A free-body diagram represents the object as a particle at the origin of a coordinate system. Force vectors are drawn with their tails on the particle. The net force vector is drawn beside the diagram.

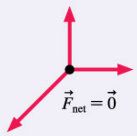


GENERAL PRINCIPLES

Two Explanatory Models

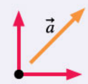
An object on which there is no net force is in **mechanical equilibrium**.

- Objects at rest.
- Objects moving with constant velocity.
- Newton's second law applies with $\vec{a} = \vec{0}$.



An object on which the net force is constant undergoes **dynamics with constant force**.

- The object accelerates.
- The kinematic model is that of constant acceleration.
- Newton's second law applies.



A Problem-Solving Strategy

A four-part strategy applies to both equilibrium and dynamics problems.

MODEL Make simplifying assumptions.

VISUALIZE

Go back and forth between these steps as needed.

- Translate words into symbols.
- Draw a sketch to define the situation.
- Draw a motion diagram.
- Identify forces.
- Draw a free-body diagram.

SOLVE Use Newton's second law:

$$\vec{F}_{net} = \sum_i \vec{F}_i = m\vec{a}$$

"Read" the vectors from the free-body diagram. Use kinematics to find velocities and positions.

ASSESS Is the result reasonable? Does it have correct units and significant figures?

IMPORTANT CONCEPTS

Specific information about three important descriptive models:

Gravity $\vec{F}_G = (mg, \text{downward})$

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

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

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

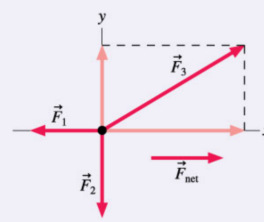
Drag $\vec{F}_{drag} = \left(\frac{1}{2}C\rho A v^2, \text{direction opposite the motion}\right)$

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

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

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

The acceleration is zero in equilibrium and also along an axis perpendicular to the motion.



APPLICATIONS

Mass is an intrinsic property of an object that describes the object's inertia and, loosely speaking, its quantity of matter.

The **weight** of an object is the reading of a spring scale when the object is at rest relative to the scale. Weight is the result of weighing. An object's weight depends on its mass, its acceleration, and the strength of gravity. An object in free fall is weightless.

A falling object reaches **terminal speed**

$$v_{term} = \sqrt{\frac{2mg}{C\rho A}}$$

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

Conceptual Questions and Example Problems from Chapters 5 and 6

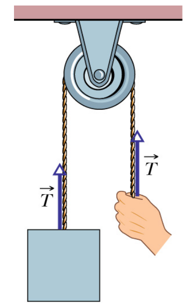
Conceptual Question 5.7

An object experiencing a constant force accelerates at 10 m/s^2. What will be the acceleration of this object be if (a) The force is doubled? Explain. (b) The mass is doubled? (c) The force is doubled *and* the mass is doubled?

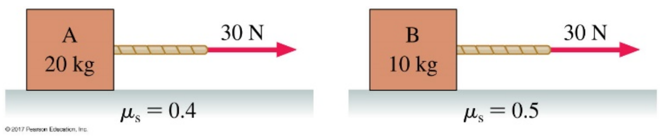
Conceptual Question 5.13

Is it possible for the friction force on an object to be in the direction of motion? If so, give an example. If not, why not?

Conceptual Question 5.A
The body that is suspended by a rope in the figure below has a weight of 75 N. Is the tension T equal to, greater than, or less than 75 N when the body is moving downward at decreasing speed?

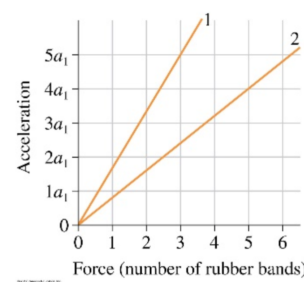


Conceptual Question 6.13
Boxes A and B in the figure below both remain at rest. Is the friction force on A larger than, smaller than, or equal to the frictional force on B? Explain.



Conceptual Question 6.A
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 f_s on the crate from the wall and (b) the normal force F_N on the crate from the wall. If you increase your push, what happens to (c) f_s, (d) F_N, and (e) $f_{s,max}$?

Problem 5.8
The figure to the right shows the acceleration-versus-force graphs for two objects pulled by rubber bands. What is the mass ratio m_1/m_2?



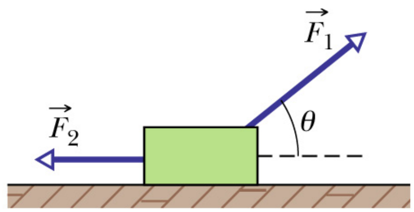
Problem 5.48
You've jumped down from a platform. Your feet are touching the ground and your knees are flexing as you stop. Draw a motion diagram, a force-identification diagram, and a free-body diagram.

Problem 5.51
A spring-loaded gun shoots a plastic ball. The trigger has just been pulled and the ball is starting to move down the barrel. The barrel is horizontal. Draw a motion diagram, a force-identification diagram, and a free-body diagram.

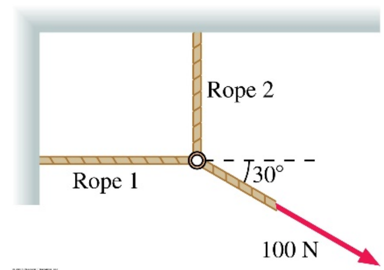
Problem 5.53
The leaf hopper, champion jumper of the insect world, can jump straight up at 4 m/s^2. The jump itself lasts a mere 1 ms before the insect is clear of the ground.

a. Draw a free-body diagram of this mighty leaper while the jump is taking place.
b. While the jump is taking place, is the force of the ground on the leaf hopper greater than, less than, or equal to the force of gravity on the leaf hopper? Explain.

Problem 6.A
In the figure below, two forces, $\vec{F}_1$ and $\vec{F}_2$, act a 50.0 kg crate that sits on a frictionless floor. The magnitude of F_1 is 255 N and it is applied at a 40° angle. The magnitude of F_2 is 55N. **(a)** What is the normal force exerted on the crate? **(b)** What is the crate's acceleration?

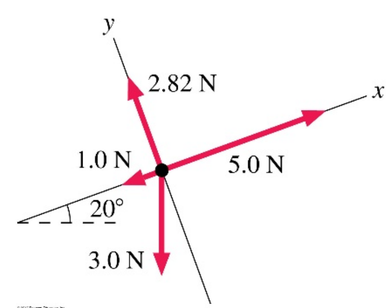


Problem 6.2
The three ropes in the figure to the right are tied to a small, very light ring. Two of the ropes are anchored to walls at right angles, and the third rope pulls as shown. What are T_1 and T_2, the magnitudes of the tension forces in the first two ropes.



Problem 6.3
A football coach sits on a sled while two of his players build their strength by dragging the sled across the field with ropes. The friction force on the sled is 1000 N, the players have equal pulls, and the angle between the two ropes is 20°. How hard must each player pull to drag the coach at a steady 2.0 m/s?

Problem 6.9
The forces in the figure to the right act on a 2.0 kg object. What are the values of a_x and a_y, the x- and y-components of the object's acceleration?



Problem 6.26
A 10 kg crate is placed on a horizontal conveyor belt. The materials are such that $\mu_s = 0.50$ and $\mu_k = 0.30$. **(a)** Draw a free-body diagram showing all the forces on the crate if the conveyor belt runs at constant speed? **(b)** Draw a free-body diagram showing all the forces on the crate if the conveyor belt is speeding up? **(c)** What is the maximum acceleration the belt can have without the crate slipping?

Problem 6.29
A 4000 kg truck is parked on a 15° slope. How big is the friction force on the truck? The coefficient of static friction between the tires and the road is 0.90.

Problem 6.32
You and your friend Peter are putting new shingles on a roof pitched at 25°. You're sitting on the very top of the roof when Peter, who is at the edge of the roof directly below you, 5.0 m away, asks you for of the box of nails. Rather than carry the 2.5 kg box of nails down to Peter, you decide to give the box of push and have it slide down to him. If the coefficient of kinetic friction between the box and the roof is 0.55, with what speed should you push the box to have it gently come to rest right at the edge of the roof.

Problem 6.34
A medium-sized jet has a 3.8-m-diameter fuselage and a loaded mass of 85,000 kg. The drag on an airplane is primarily due to the cylindrical fuselage, and the aerodynamic shaping gives it a drag coefficient of 0.37. How much thrust must the jet's engines provide to cruise at 230 m/s at an altitude where the air density is 1.0 kg/m^3?

Problem 6.36
A 6.5-cm-diameter ball has a terminal speed of 26 m/s. What is the balls mass?

Problem 6.50
A baggage handler drops your 10 kg suitcase onto a conveyor belt running at 2.0 m/s. The materials are such that $\mu_s = 0.50$ and $\mu_k = 0.30$. How far is your suitcase dragged before it is riding smoothly on the belt?

Problem 6.52
It's a snowy day and you're pulling a friend along a level road on a sled. You've both been taking physics, so she asks what you think the coefficient of friction between the sled and the snow is. You've been walking at a steady 1.5 m/s, and the rope pulls up on the sled at a 30° angle. You estimate that the mass of the sled, with your friend on it, is 60 kg and that you're pulling with a force of 75 N. **(a)** What answer will you give? **(b)** Does the calculated coefficient of friction reasonable? Explain.