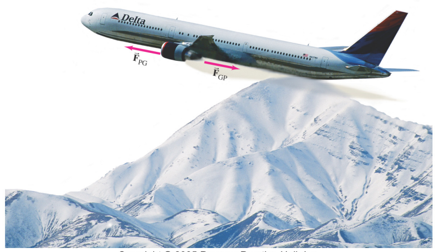
Chapter 4

Dynamics: Newton's Laws of Motion



Units of Chapter 4

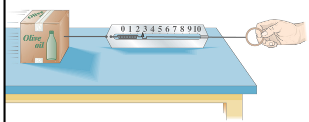
- Force
- Newton's First Law of Motion
- Mass
- Newton's Second Law of Motion
- Newton's Third Law of Motion
- Weight – the Force of Gravity; and the Normal Force

Units of Chapter 4

- Solving Problems with Newton's Laws: Free-Body Diagrams
- Applications Involving Friction, Inclines
- Problem Solving – A General Approach

4-1 Force

A **force** is a **push** or **pull**. An object at rest needs a force to get it **moving**; a moving object needs a force to change its **velocity**.

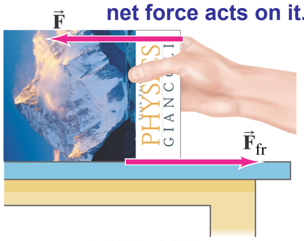


The **magnitude** of a force can be measured using a spring scale.

4-2 Newton's First Law of Motion

Newton's **first law** is often called the law of **inertia**.

Every object continues in its state of rest, or of uniform velocity in a straight line, as long as no net force acts on it.



4-2 Newton's First Law of Motion

Inertial **reference frames:**

An inertial reference frame is one in which **Newton's first law** is valid.

This excludes **rotating** and **accelerating** frames.

4-3 Mass

Mass is the measure of inertia of an object. In the SI system, mass is measured in **kilograms**.

Mass is not **weight**:

Mass is a **property** of an object. Weight is the **force** exerted on that object by gravity.

If you go to the moon, whose gravitational acceleration is about 1/6 *g*, you will weigh much less. Your mass, however, will be the same.

4-4 Newton's Second Law of Motion

Newton's **second law** is the relation between **acceleration** and **force**. Acceleration is proportional to force and inversely proportional to mass.

$$\Sigma \vec{F} = m\vec{a} \quad (4\text{-}1)$$

4-4 Newton's Second Law of Motion

Force is a **vector**, so $\Sigma \vec{F} = m\vec{a}$ is true along each coordinate axis.

TABLE 4–1
Units for Mass and Force

System	Mass	Force
SI	kilogram (kg)	newton (N) $(= kg \cdot m/s^2)$
cgs	gram (g)	dyne $(= g \cdot cm/s^2)$
British	slug	pound (lb)

Conversion factors: 1 dyne $= 10^{-5}$ N; 1 lb $\approx$ 4.45 N.

The unit of force in the SI system is the **newton** (N).

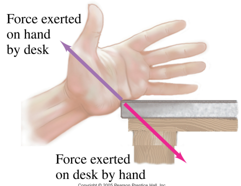
Note that the **pound** is a unit of **force**, not of mass, and can therefore be equated to newtons but not to kilograms.

4-5 Newton's Third Law of Motion

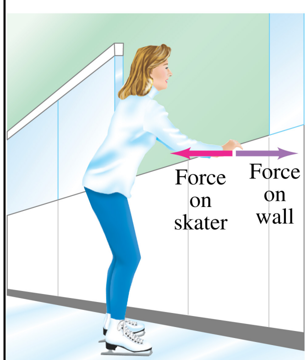
Any time a **force** is exerted on an object, that force is caused by another object.

Newton's **third law:**

Whenever one object exerts a **force** on a second object, the second exerts an equal force in the **opposite direction** on the first.



4-5 Newton's Third Law of Motion



A key to the correct application of the third law is that ***the forces are exerted on different objects***. Make sure you don't use them as if they were acting on the ***same*** object.

4-5 Newton's Third Law of Motion

Rocket propulsion can also be explained using Newton's third law: hot gases from combustion spew out of the tail of the rocket at high speeds. The **reaction force** is what propels the rocket.

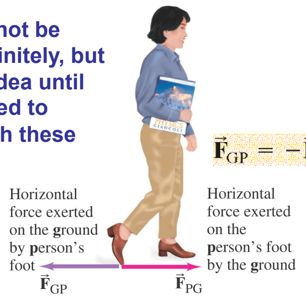
Note that the rocket does not need anything to "push" against.

4-5 Newton's Third Law of Motion

Helpful notation: the first **subscript** is the object that the force is being exerted on; the second is the source.

This need not be done indefinitely, but is a good idea until you get used to dealing with these forces.

$$\vec{F}_{GP} = -\vec{F}_{PG} \quad \text{(4-2)}$$



4-6 Weight – the Force of Gravity; and the Normal Force

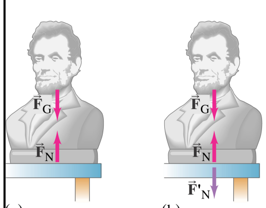
Weight is the force exerted on an object by gravity. Close to the surface of the Earth, where the gravitational force is nearly constant, the weight is:

$$\vec{F}_G = m\vec{g}$$

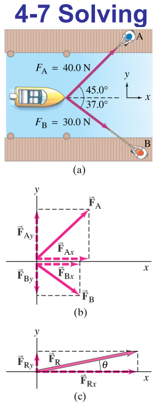
4-6 Weight – the Force of Gravity; and the Normal Force

An object at rest must have no **net force** on it. If it is sitting on a table, the force of gravity is still there; what other force is there?

The force exerted perpendicular to a surface is called the **normal force**. It is exactly as large as needed to balance the force from the object (if the required force gets too big, something breaks!)

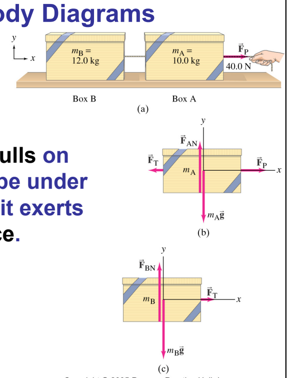


4-7 Solving Problems with Newton's Laws Free-Body Diagrams



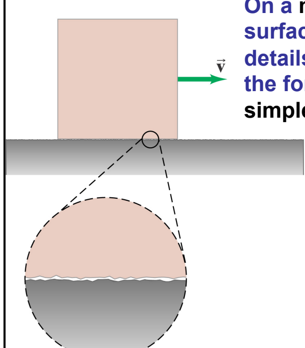
1. Draw a **sketch**.
2. For one object, draw a **free-body diagram**, showing all the forces acting *on* the object. Make the **magnitudes** and **directions** as accurate as you can. **Label** each force. If there are multiple objects, draw a separate diagram for each one.
3. **Resolve** vectors into components.
4. Apply **Newton's second law** to each component.
5. Solve.

4-7 Solving Problems with Newton's Laws – Free-Body Diagrams



When a cord or rope **pulls** on an object, it is said to be under **tension**, and the force it exerts is called a **tension force**.

4-8 Applications Involving Friction, Inclines



On a **microscopic** scale, most surfaces are rough. The exact details are not yet known, but the force can be modeled in a **simple** way.

For **kinetic** – sliding – friction, we write:

$$F_{fr} = \mu_k F_N$$

μ_k is the coefficient of **kinetic** friction, and is different for every pair of surfaces.

4-8 Applications Involving Friction, Inclines

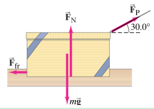


TABLE 4–2 Coefficients of Friction†

Surfaces	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Wood on wood	0.4	0.2
Ice on ice	0.1	0.03
Metal on metal (lubricated)	0.15	0.07
Steel on steel (unlubricated)	0.7	0.6
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Rubber on other solid surfaces	1–4	1
Teflon® on Teflon in air	0.04	0.04
Teflon on steel in air	0.04	0.04
Lubricated ball bearings	<0.01	<0.01
Synovial joints (in human limbs)	0.01	0.01

† Values are approximate and intended only as a guide.

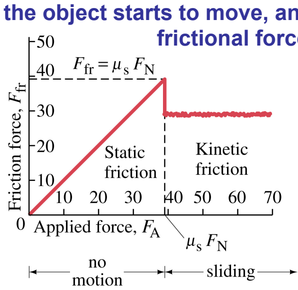
4-8 Applications Involving Friction, Inclines

Static friction is the frictional force between two surfaces that are **not** moving along each other. Static friction keeps objects on inclines from sliding, and keeps objects from moving when a force is first applied.

$$F_{fr} \leq \mu_s F_N$$

4-8 Applications Involving Friction, Inclines

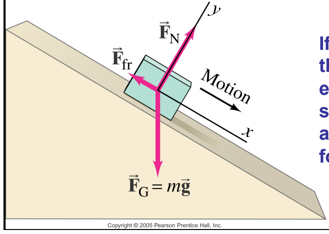
The static frictional force **increases** as the applied force increases, until it reaches its **maximum**. Then the object starts to move, and the **kinetic** frictional force takes over.



4-8 Applications Involving Friction, Inclines

An object sliding down an incline has three forces acting on it: the **normal** force, **gravity**, and the **frictional** force.

- The normal force is always **perpendicular** to the surface.
- The friction force is **parallel** to it.
- The gravitational force points **down**.



If the object is at rest, the forces are the same except that we use the static frictional force, and the sum of the forces is zero.

4-9 Problem Solving – A General Approach

1. **Read** the problem carefully; then read it again.
2. **Draw** a sketch, and then a free-body diagram.
3. Choose a convenient **coordinate system**.
4. List the **known** and **unknown** quantities; find **relationships** between the knowns and the unknowns.
5. **Estimate** the answer.
6. Solve the problem without putting in any numbers (**algebraically**); once you are satisfied, put the **numbers** in.
7. Keep track of **dimensions**.
8. Make sure your answer is **reasonable**.

Summary of Chapter 4

- Newton's first law: If the net force on an object is zero, it will remain either at rest or moving in a straight line at constant speed.
- Newton's second law: $\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}}$
- Newton's third law: $\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}$
- Weight is the gravitational force on an object.
- The frictional force can be written: $F_{fr} = \mu_k F_N$ (kinetic friction) or $F_{fr} \leq \mu_s F_N$ (static friction)
- Free-body diagrams are essential for problem-solving