Chapter 5

Newton's Laws of Motion

Pui K. Lam 7_8_2018

Learning Goals for Chapter 5 − Newton's Laws

- Recognize that forces arise from interaction between objects
- Learn to identify action–reaction force pair and their corresponding interaction - Newton's Third Law
- Learn to identify all forces acting on a body, able to draw "free-body" diagrams.
- Learn the relationship between net force vector and acceleration vector: Newton's First Law and Second Law

Where do forces come from?

- A force exerting on a body (A) must come from an interaction with some other body (B)

  A--->   <---B

  (Thus, forces come in pair; force on A by B, F_{AB}, and force on B by A, F_{BA}.)

- There are 4 (known) fundamental interactions: (gravitational, electromagnetic, strong nuclear, and weak nuclear interactions), hence there are 4 (known) fundamental forces.

- When identifying a force on a body, one should be able to complete the following statement:

  Force on ___ by ___ due to ___________ interaction.

  e.g. There is a force on the Earth by the Sun due to gravitational interaction.

If you cannot complete such a statement, probably there is no such force!!

"Action-Reaction" force pairs

- Example: The gravitational interaction between the Earth and the Sun give rise to a force on the Earth as well as a force on the Sun. That is,

there is a force on the Earth by the Sun due to gravitational interaction, AND,

there is a force on the Sun by the Earth due to the SAME gravitational interaction

Newton's 3rd Law: The "action-reaction forces are EQUAL IN MAGNITUDE but OPPOSITE IN DIRECTION.

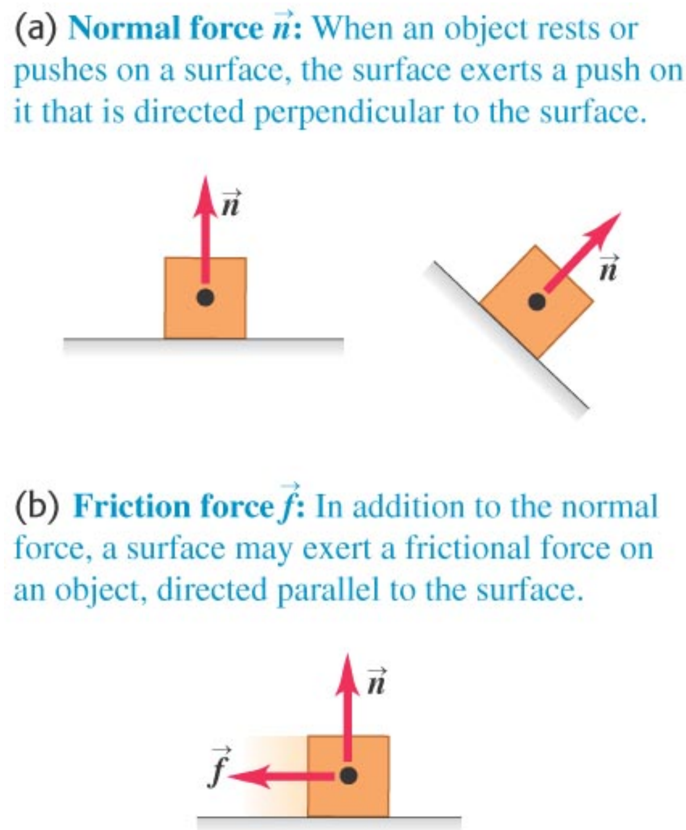
$$i.e.\quad \vec{F}_{S/E} = -\vec{F}_{E/S}$$

Gravitational force and electromagnetic force

- The two forces that we will be dealing with in PHYSICS 170 are gravitational and electromagnetic forces.
- Properties of gravitational force:
  - It is an attractive force between any two masses.
  - The two masses need not be in contact (action at a distance).
- Properties of electromagnetic force:
  - Repulsive forces between like charges and attractive force between unlike charges
  - Charges need not be in contact, **HOWEVER,** most objects are neutral (equal number of positive and negative charges), hence there is no net electromagnet force between them when they are far apart. However, when they are in **"contact",** the electromagnet forces between the charges do not cancel exactly and there is a net electromagnetic force. Most textbooks refer to this force as the "contact" force.

Examples of “contact” forces

- When an object rests or pushes on a surface, the surface pushes back - this “contact” force is called the “normal” force; it is perpendicular to the surface
- In addition to the normal force, surfaces can resist motion along the surface - this is called the frictional force (or simply friction)



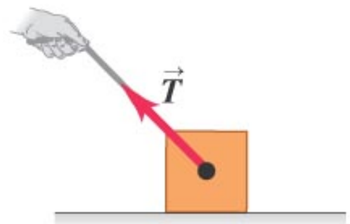
Comparing "contact" force with gravitational force

- Tension forces—When a force is exerted through a rope or cable, the force is transmitted through that rope or cable as a tension; **the rope must be in contact with the object.**

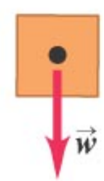
- Weight—Gravitational force on an object (exerted by the Earth or other large mass); the two masses need not be in contact.

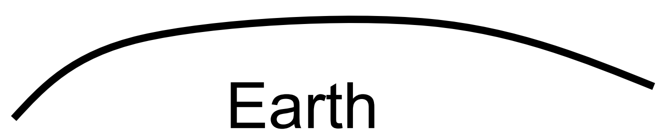
- *Note: **For this course**, the only non-contact force on an object is due to gravity, all the other forces on an object MUST come from something in "contact" with the object.*

(c) **Tension force $\vec{T}$:** A pulling force exerted on an object by a rope, cord, etc.



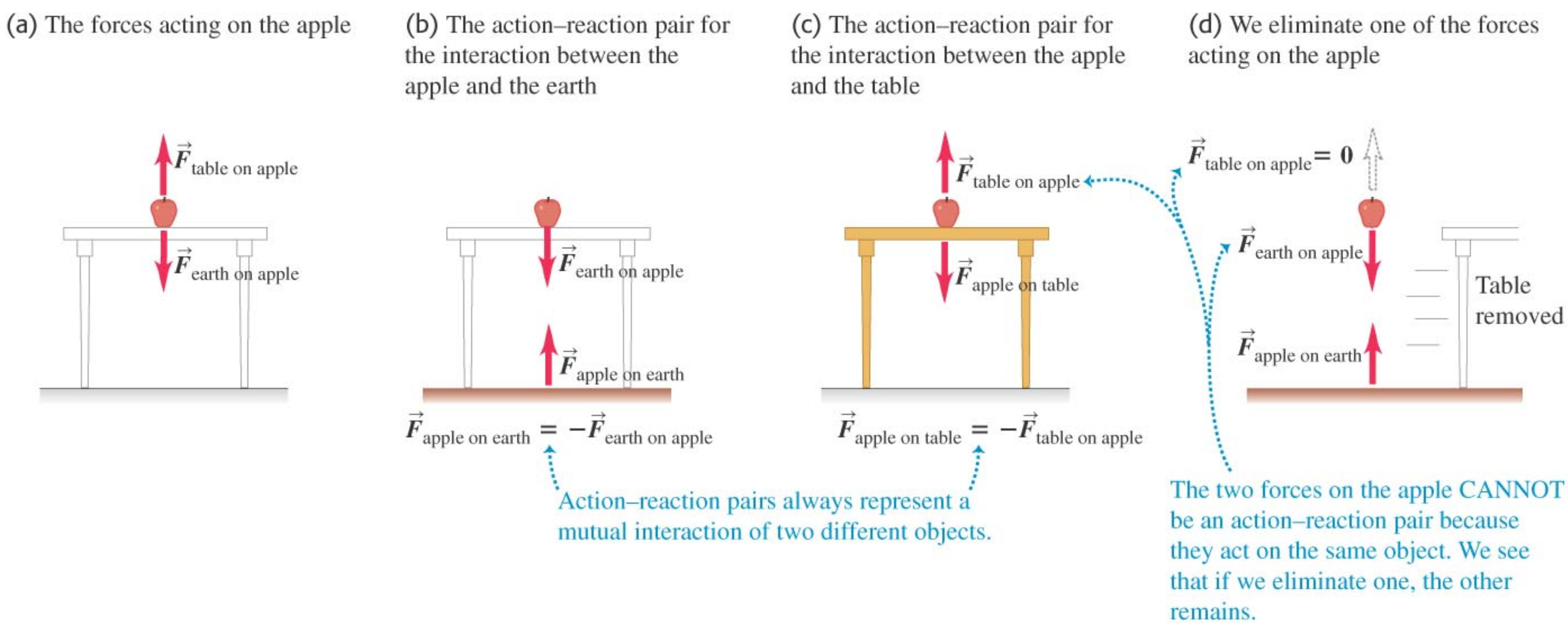
(d) **Weight $\vec{w}$:** The pull of gravity on an object is a long-range force (a force that acts over a distance).





Newton's Third Law—Identify action-reaction pair

- Correct and incorrect identification action-reaction pair.



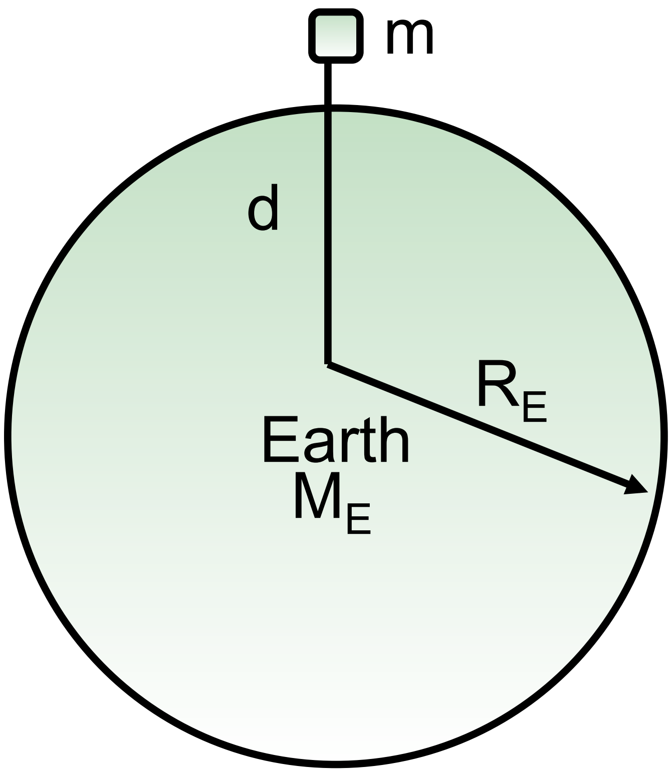
Action-reaction pair do NOT act on the same object!

An object's weight – gravitational interaction

- The weight of an object on Earth = force on the object (m) by Earth (M_E) due to gravitational interaction.
- According to Newton's Law of Gravitation (Chapter 12), this force is given by:

$$w = \frac{GM_E m}{d^2} \approx m\left(\frac{GM_E}{R_E^2}\right) \equiv mg,$$

$$g = \left(\frac{GM_E}{R_E^2}\right) \approx 9.8\,\frac{m}{s^2}$$



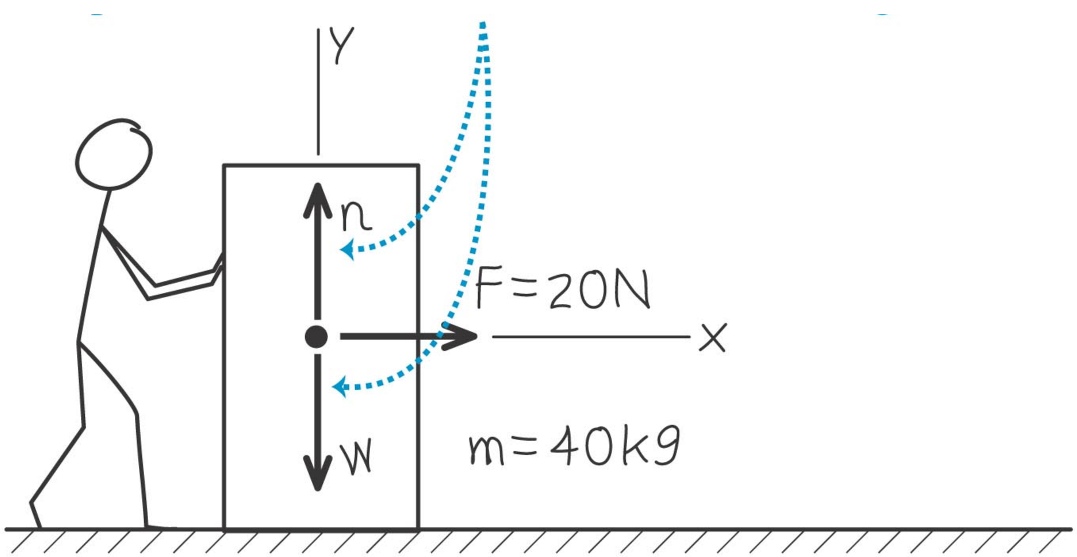
Note: The weight of an object depends on how far it is from the center of the Earth, but the mass remains the same.

Question: What is the weight of a 1-kg mass near the surface of the Earth?

Question: What is the weight of a 1-kg mass at a distance above Earth surface equals to the radius of the Earth?

"Free-Body Diagram"

- A diagram showing all the forces acting on an object (one object) is called the "free-body diagram" for that object.
- If you want to study several objects in contact, you need to draw a free-body diagram for each object.



Example: We are interested in the forces acting on the crate.

The crate is in contact with the floor
=> n force

The crate is in contact with the man
=> F=20 N

The crate interacts with the Earth
=> w=mg

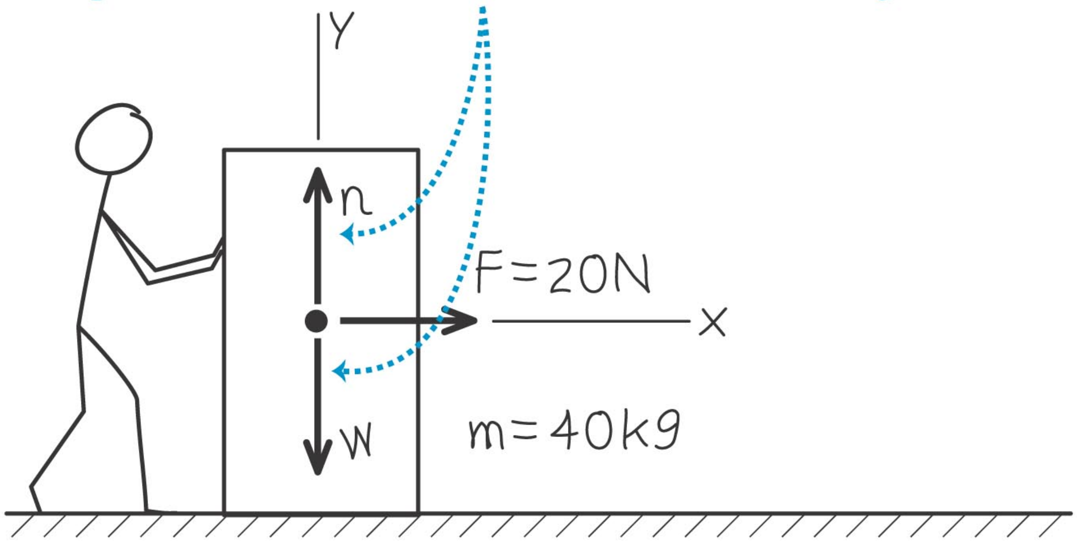
"Free-Body Diagram"

Task: Now, draw a free body diagram for the man (mass of man=70 kg).

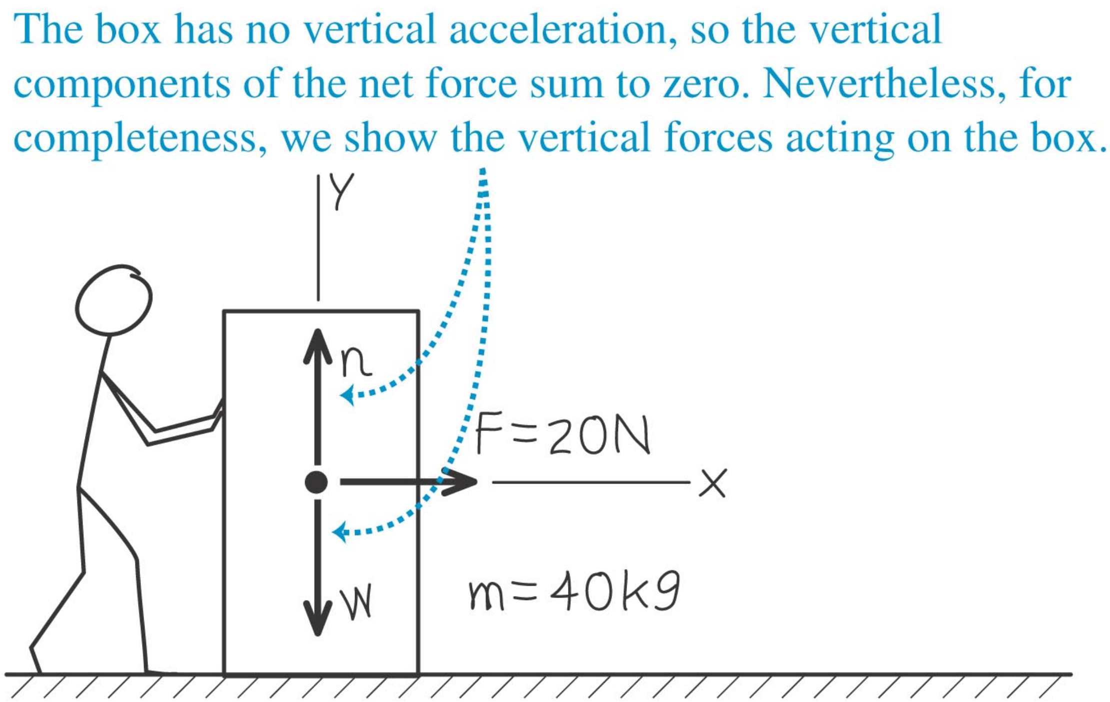
For every force, complete the statement:

Force on_______ by _______ due to _________ interaction.

The box has no vertical acceleration, so the vertical components of the net force sum to zero. Nevertheless, for completeness, we show the vertical forces acting on the box.



Relationship between force and acceleration?



The man pushes on the crate
the crates starts to accelerate
Need to know
the relationship between force and acceleration
- Newton's Law of Motion

Newton's First Law of Motion

- In mathematical terms:

First Law:

If net $\vec{F}$ on an object =0,

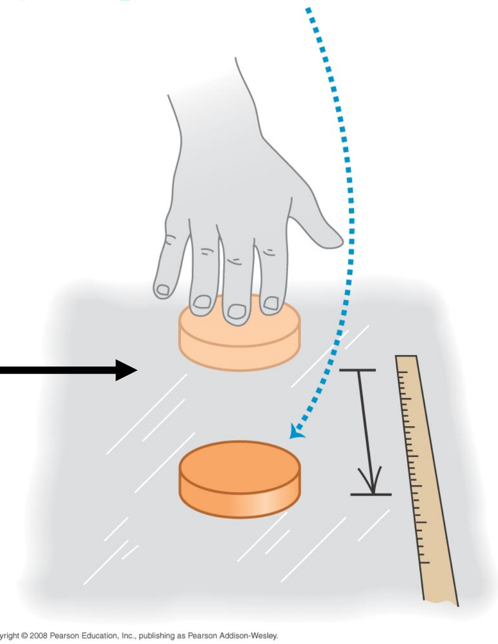
then $\vec{a}$ of the object=0

$\Rightarrow \vec{v}$ of the object = constant

(the constant can be zero or non-zero)

Once the pucks leaves your hand, there is zero net force on the pucks (if there is no friction), then the puck will move at a constant velocity

(b) Ice: puck slides farther.



Newton's Second Law of Motion

- In mathematical terms:

Second Law:

If the net force on an object is not zero,then

the acceleration of an object (whose mass is m)

is given by:

$$\text{net } \vec{F} = m\,\vec{a}$$

Note : This is a vector equation

$$\Rightarrow \text{net } F_x = ma_x$$

$$\text{net } F_y = ma_y$$

$$\text{net } F_z = ma_z$$

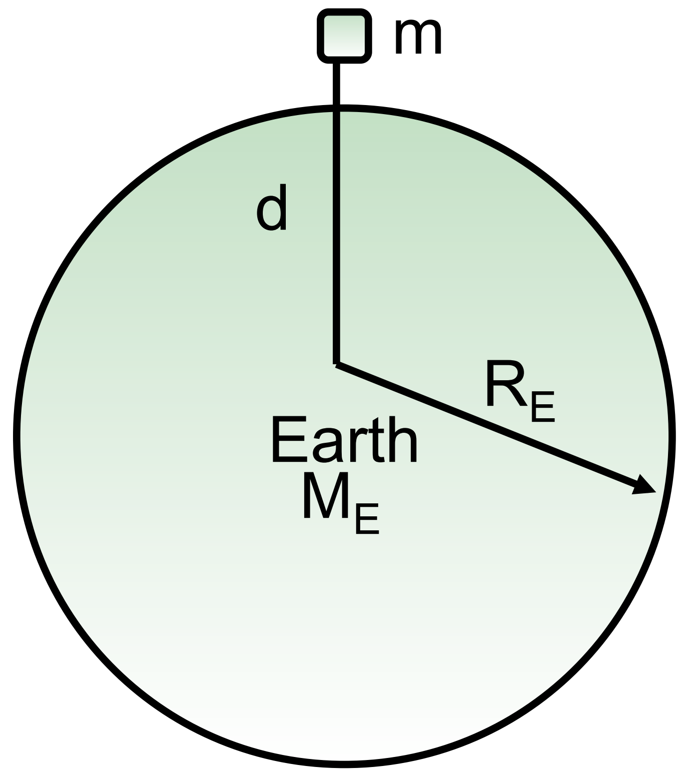
It also implies that the accelertation vector is

in the same direction of the net force vector.

Apply Newton's Second Law to Free-fall

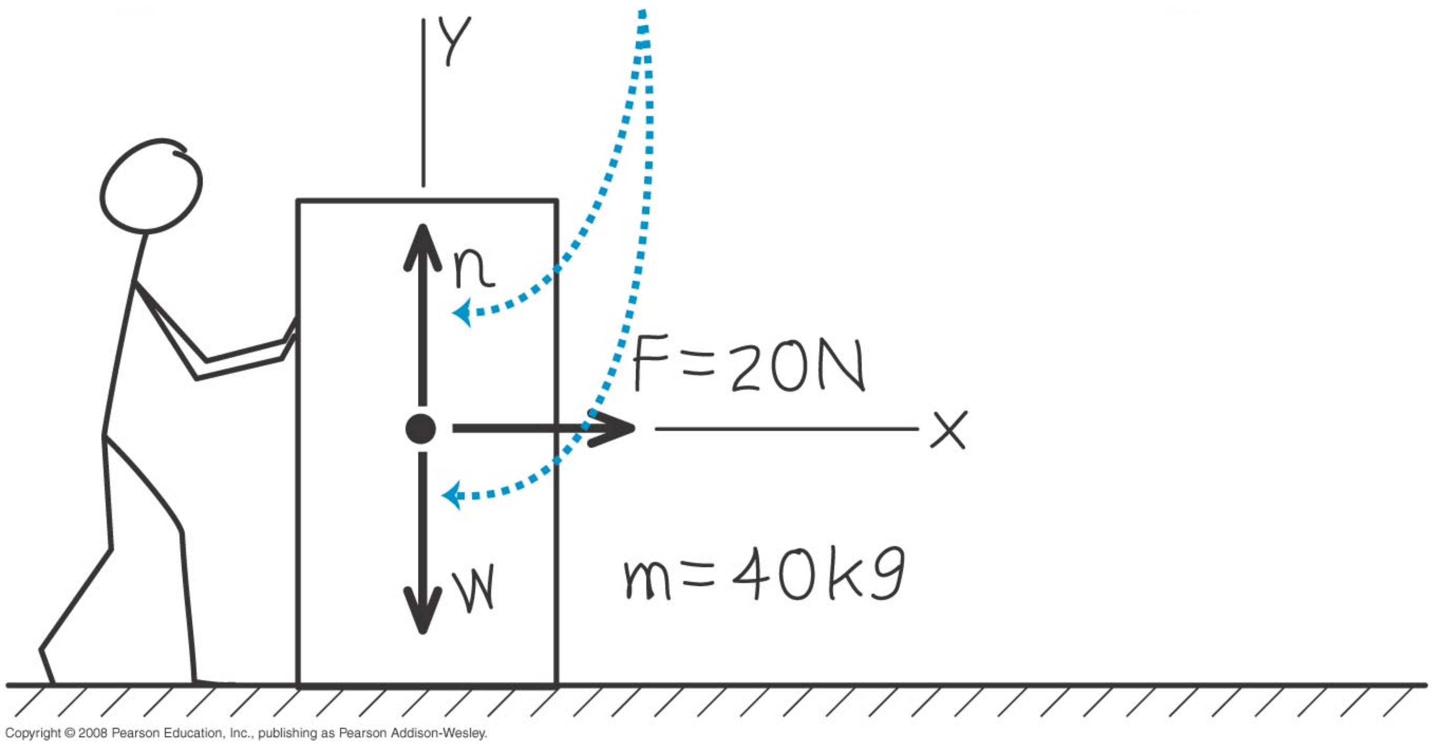
Draw a free-body diagram for an object in free fall with mass=m.

Apply Newton second law to find the object's acceleration.



Apply Newton's Second Law—quantitative, Example 4.4, P.119

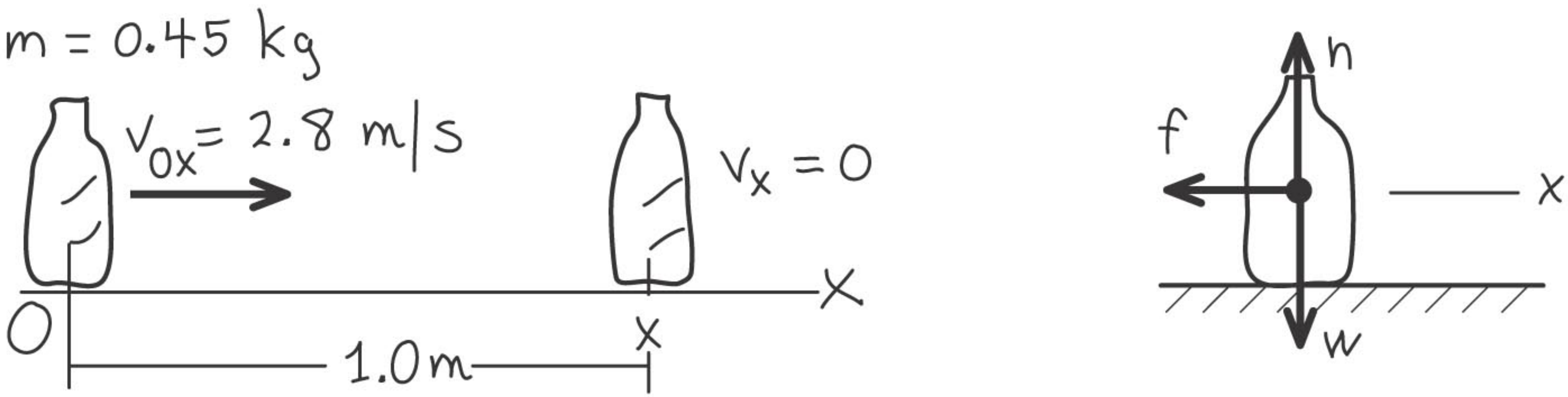
- Assume there is no friction between the floor and the crate, find w, n, and the acceleration vector of the mass.



Using Newton's Second Law II—Example 4.5

- Calculate the frictional force (f).

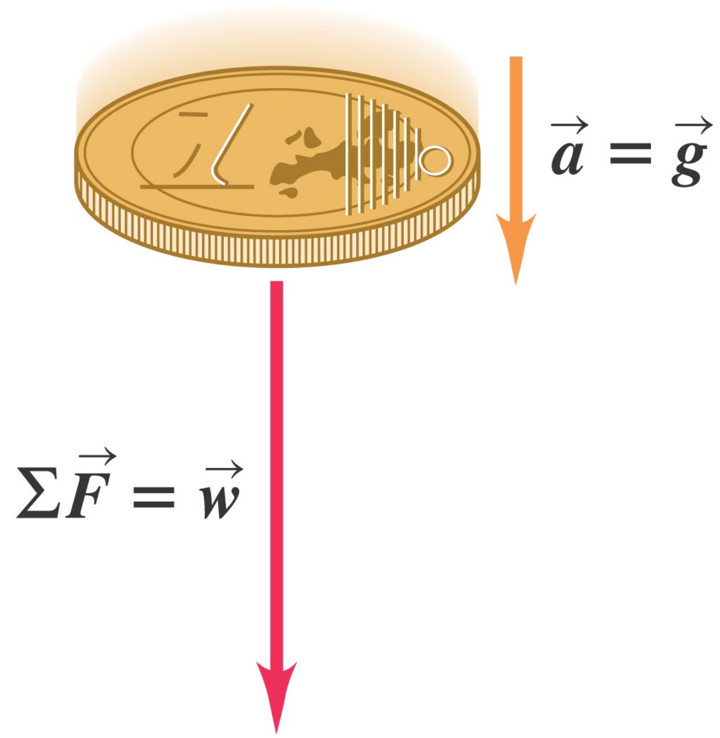
We draw one diagram for the bottle's motion and one showing the forces on the bottle.



Hint: What is the "acceleration" of the bottle?
To stop the bottle in a shorter distance, the frictional force needs to be larger or smaller?

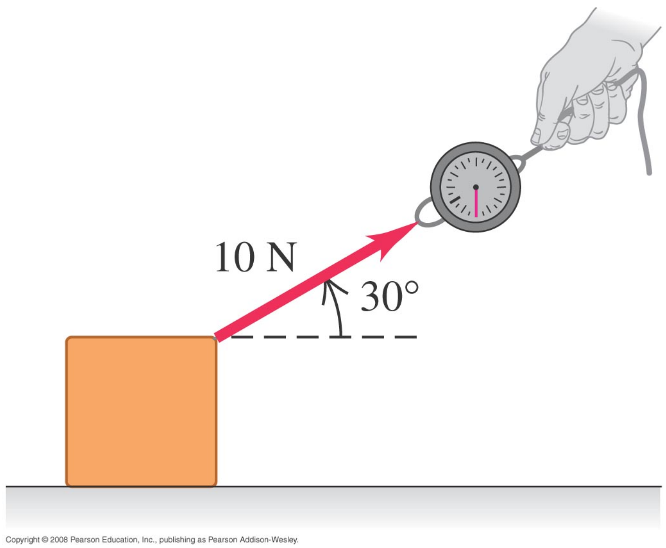
Many have asked "how lethal is a coin dropped from atop a tall building"?

- Urban legends have said that a penny dropped from the top of the Empire State Building can kill.
- Conceptual Example 4.6 in the text DID NOT address this legend. Consider the following statement: The coin weighs only a few ounces, how can a few ounces of force kill you??
- **Use the example in the previous slide to explain this.**

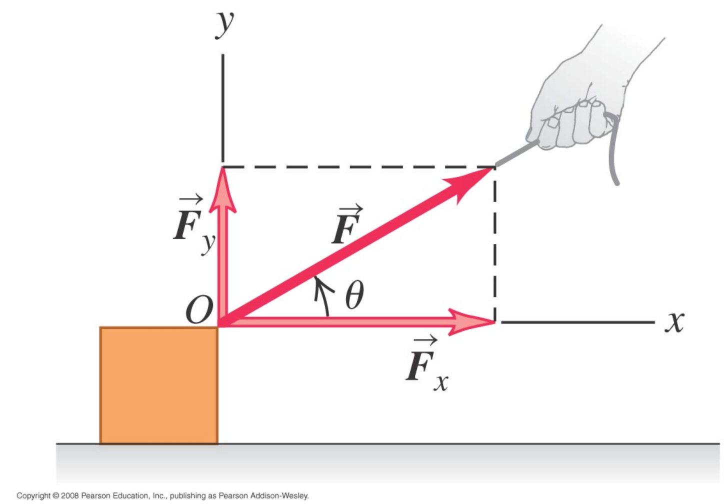


Force acting at an angle

(a) A 10-N pull directed 30° above the horizontal



(a) Component vectors: $\vec{F}_x$ and $\vec{F}_y$
Components: $F_x = F \cos \theta$ and $F_y = F \sin \theta$



Let the mass of the block be 10 kg.

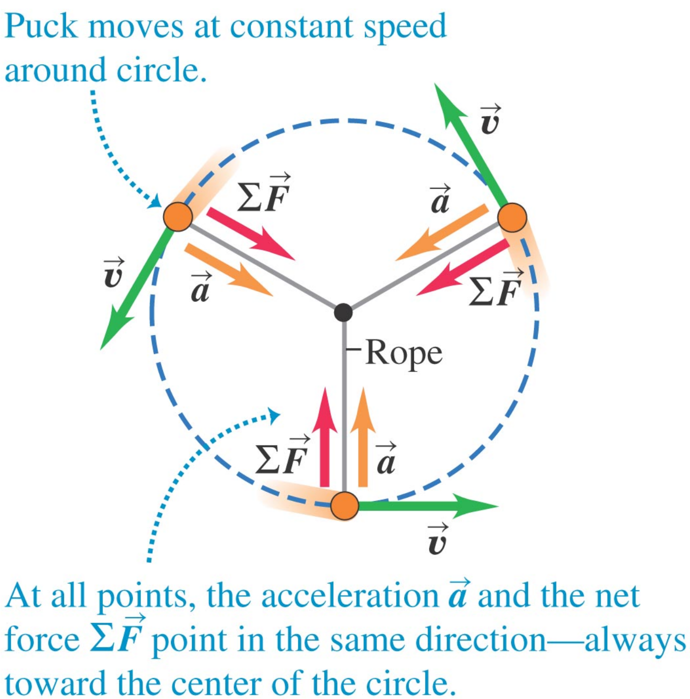
Assume no friction, find

(1) The magnitude of the normal force.

(2) The acceleration vector of the block.

Apply Newton's Second Law to circular motion - qualitative.

- Tie a rope to a puck and swirl it around.



- Based on kinematics, we know that the puck has a centripetal acceleration (pointing inward). Now we know that this centripetal acceleration is provided by the rope pulling on the puck. Same explanation for the Earth going around the Sun; the gravitation force provides the centripetal acceleration.

Inertial frames of reference

- The motion of an object may be observed by someone standing on Earth, or someone riding in a train or someone inside a spacecraft. Each observer uses his/her own coordinate system. These different systems constitute different "frames of reference".
- Newton's First Law (and Second Law) is only valid in some special kind of reference frames called the inertial reference frame.
- The definition of inertial reference frame is rather a circular one: "A reference frame where Newton's First Law is valid is called the inertial reference frame".
- Qualitatively, an inertial reference frame is an "unbiased frame" such as a spaceship in deep space with its engine turned off.
- An example of an non inertial reference frame is an observer inside a car which going around a curve .