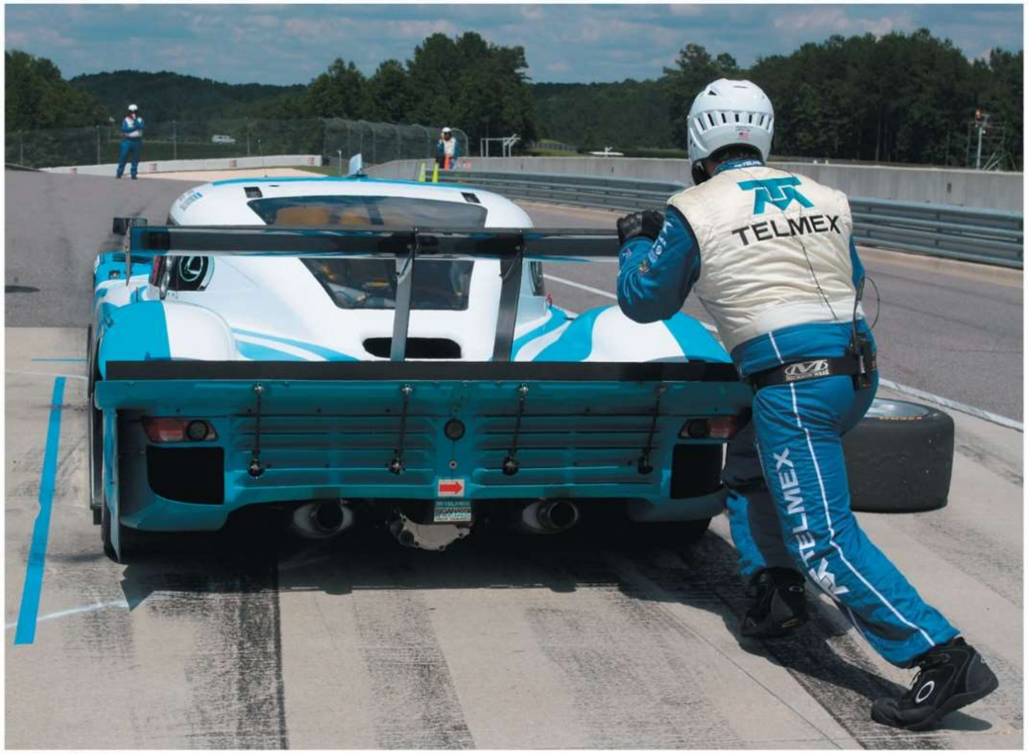
Chapter 4

Newton's Laws of Motion



Overview of Chapter 4

In previous chapter we saw how objects move once we know the acceleration. Next we need to understand where that acceleration comes from. This is the connection between kinetics and dynamics (forces and accelerations).

Concept of Force
<u>Newton's Laws of Motion</u>
Mass
Normal Force
Example problems

Why do you care? Different questions:

- <u>Old:</u> What acceleration needed to go from 0 to 60mi/hr in 6 sec?
- <u>New:</u> How much force does your car engine need to exert?

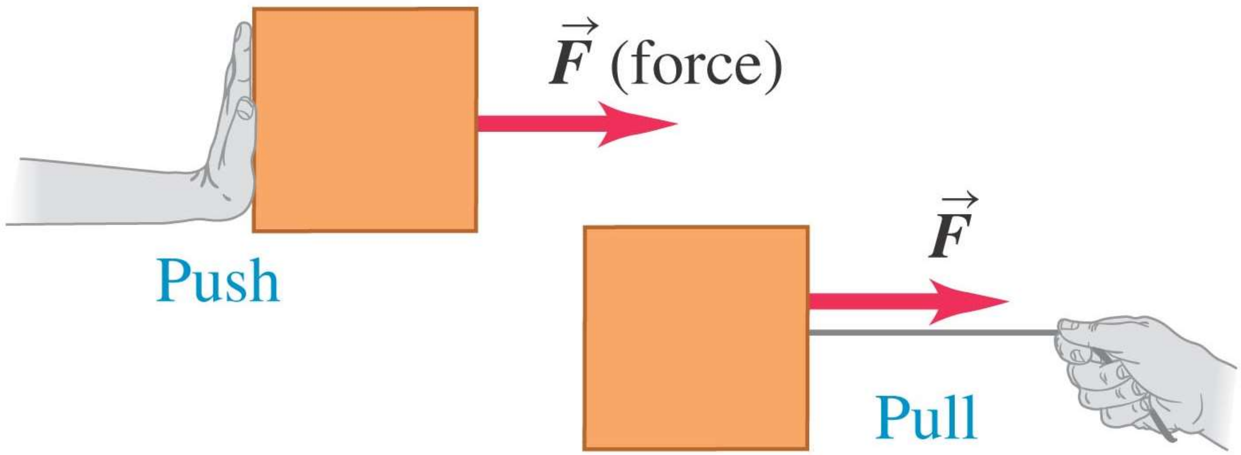
Chapter 4: focuses on introducing the concepts,
Chapter 5: Application to various examples and problems

Force: Our First Concept

What is a *Force?*

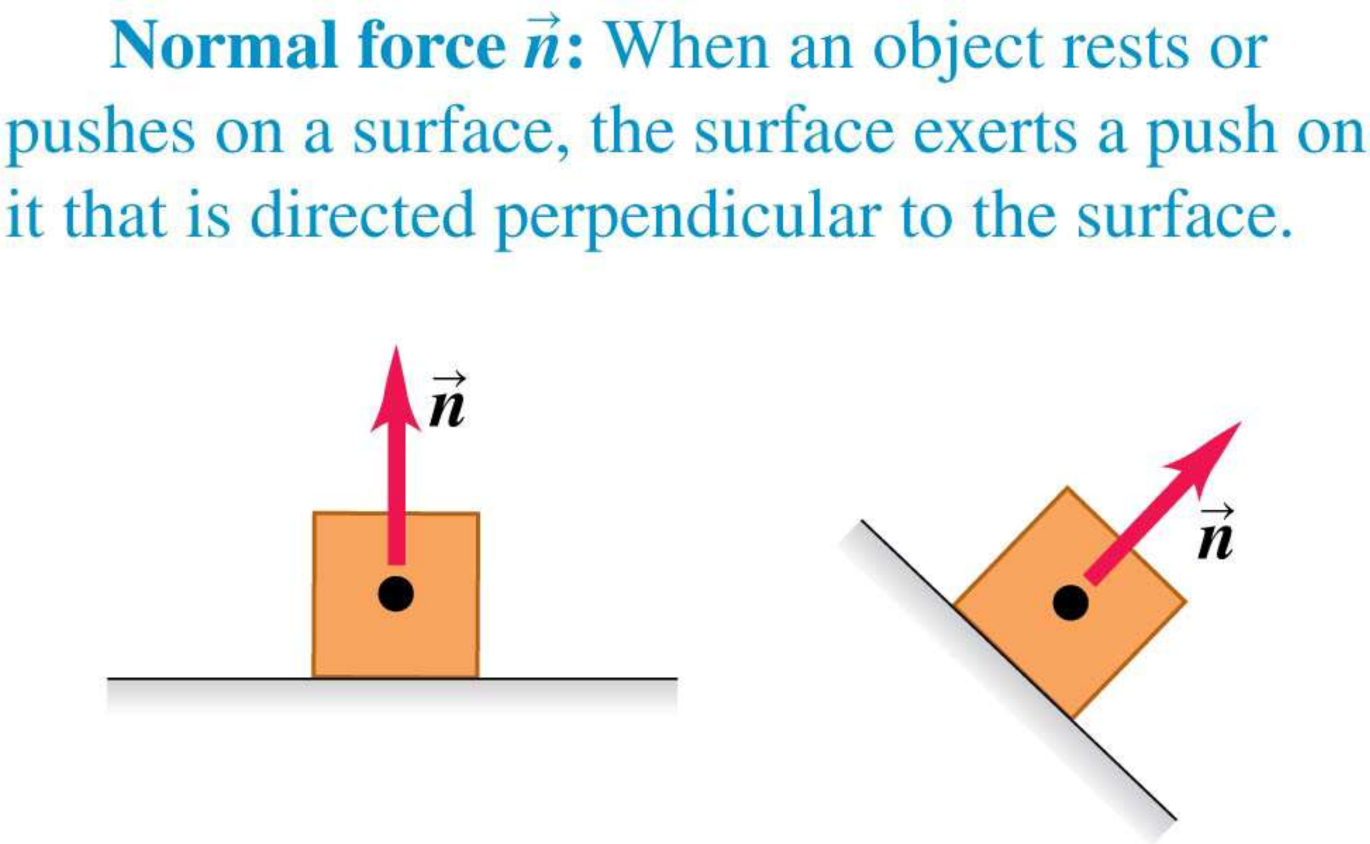
Examples:

- Push
- Pull
- Slap
- Gravity
- Others?



TWO TYPES: contact forces and forces at a distance

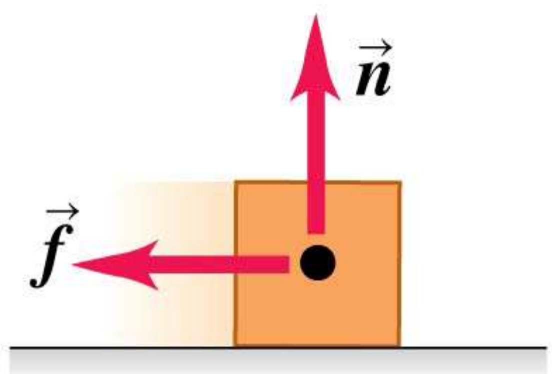
There are four common types of forces: Normal



The normal force is a contact force.

There are four common types of forces: Friction

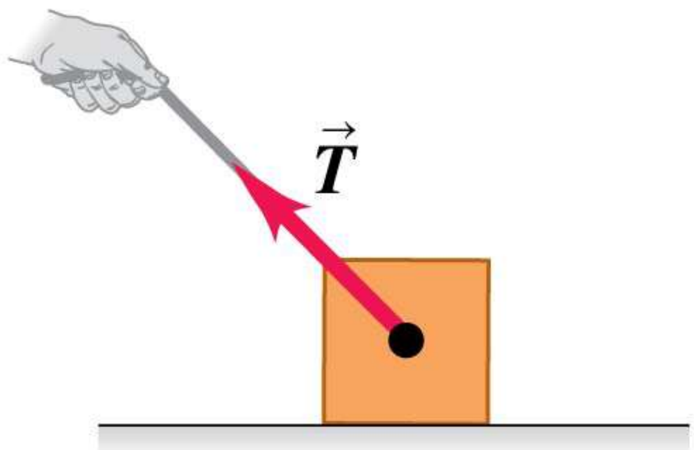
Friction force $\vec{f}$: In addition to the normal force, a surface may exert a friction force on an object, directed parallel to the surface.



Friction is a contact force.

There are four common types of forces: Tension

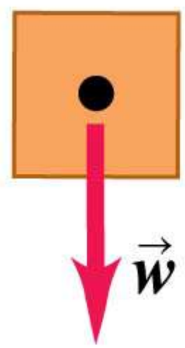
Tension force $\vec{T}$: A pulling force exerted on an object by a rope, cord, etc.



Tension is a contact force.

There are four common types of forces: Weight

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



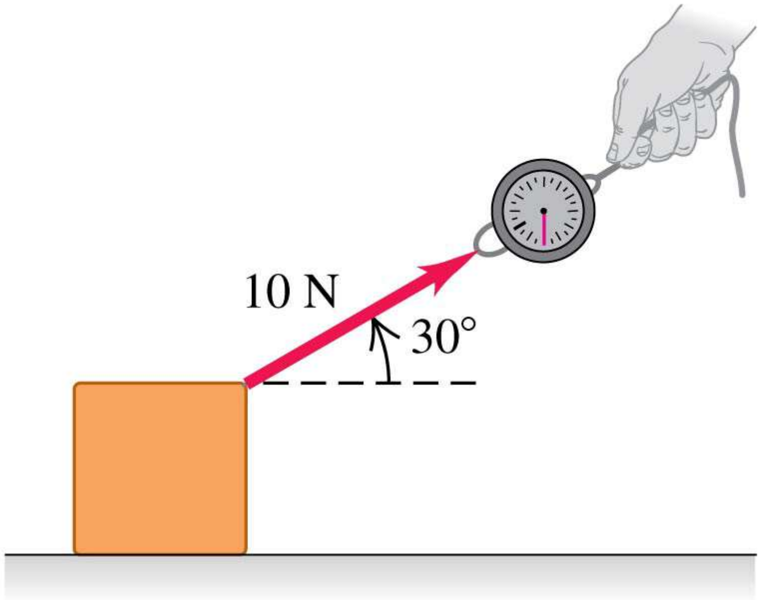
Weight is a long-range force.

Drawing force vectors

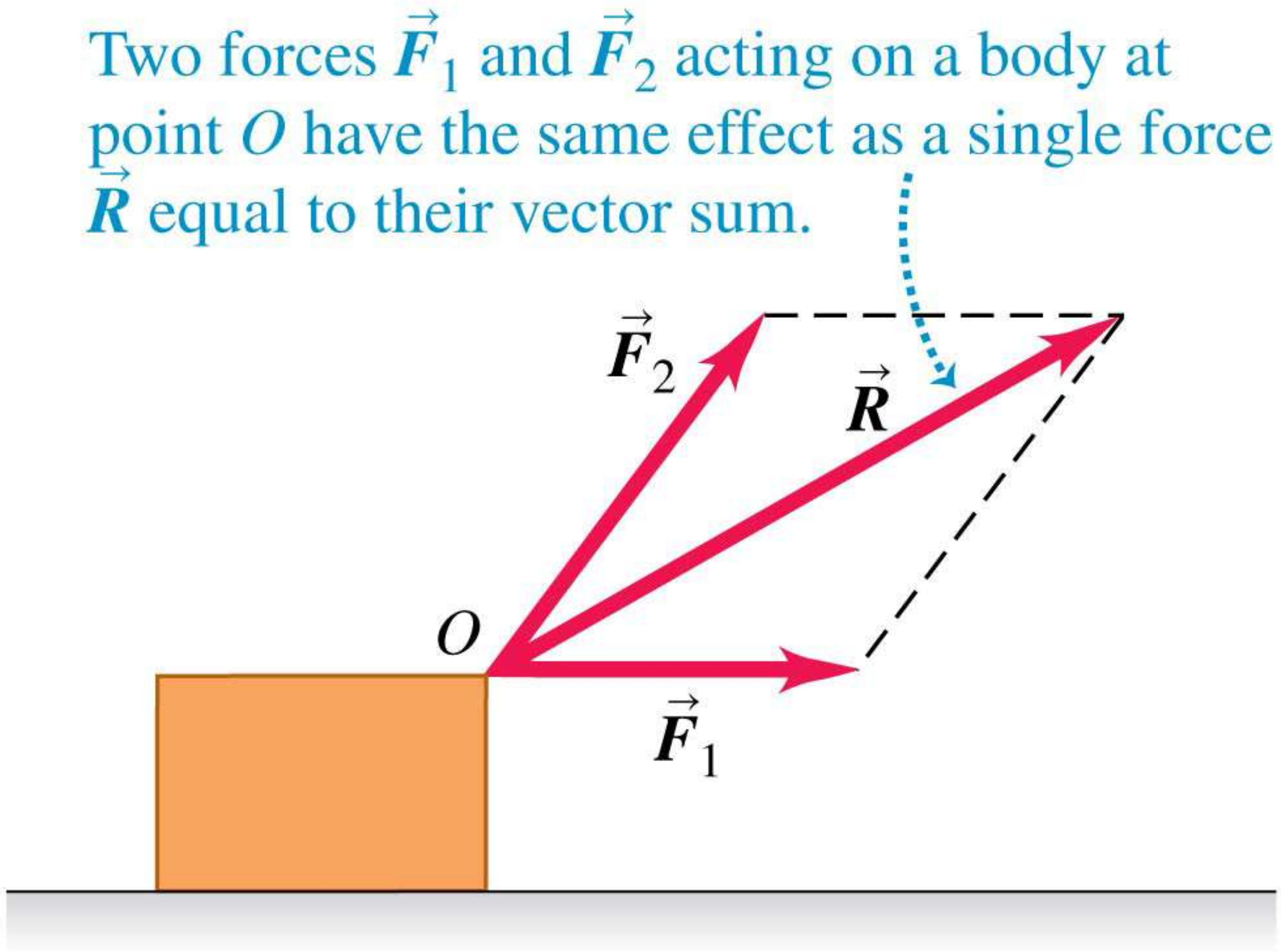
The figure shows a spring balance being used to measure a pull that we apply to a box.

We draw a vector to represent the applied force.

The length of the vector shows the magnitude; the longer the vector, the greater the force magnitude.

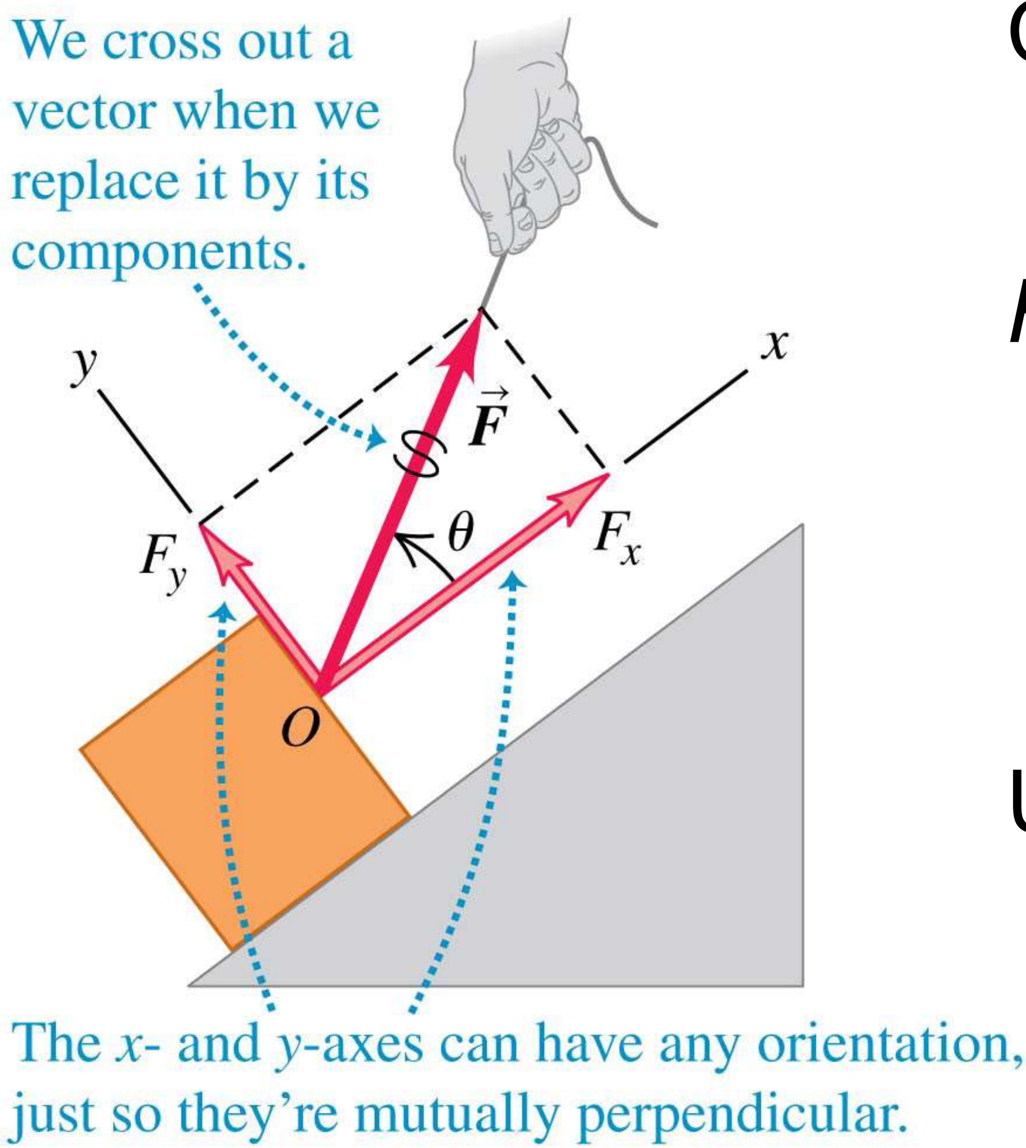


Superposition of forces



Several forces acting at a point on an object have the same effect as their vector sum acting at the same point.

Decomposing a force into its component vectors



Choose perpendicular x- and y-axes.

F_x and F_y are the components of a force along these axes.

Use trigonometry to find these force components.

Newton’s First Law

“An object continues in it’s state of rest or of uniform velocity in a straight line unless acted on by a non-zero net force”

Inertia

Translate that into English: Force

To *cause* an acceleration *(change the velocity)* requires a *Net Force*

or

If there *is* an acceleration, there *must be* a net Force

Force is a Vector

Add up all the forces (vectors) to find the Net (or total) force

Newton's First Law

Example of zero net force

- Car just sitting on the pavement
  - No velocity, no acceleration→ no net force
- A car going at a constant velocity
  - The engine IS pushing on the car BUT the air resistance and ground are also pushing such that there is no net force on the car.

Example of non-zero net forces :

- Friction: Makes a moving block slow down
- Gravity: Makes a ball fall toward the earth

Newton’s First Law

Newton’s First Law is one that tells you the state of the **net** forces on an object BECAUSE it has no acceleration (in a particular direction).

It says NOTHING about each of the forces on an object, it just says that they add up to zero.

Here the consequence tells you the result; there is no other possibility for that consequence.

When is Newton's first law valid?

Suppose you are in a bus that is traveling on a straight road and speeding up.

If you could stand in the aisle on roller skates, you would start moving *backward* relative to the bus as the bus gains speed.

It looks as though Newton's first law is not obeyed; there is no net force acting on you, yet your velocity changes.

The bus is accelerating with respect to the earth and is not a suitable frame of reference for Newton's first law.

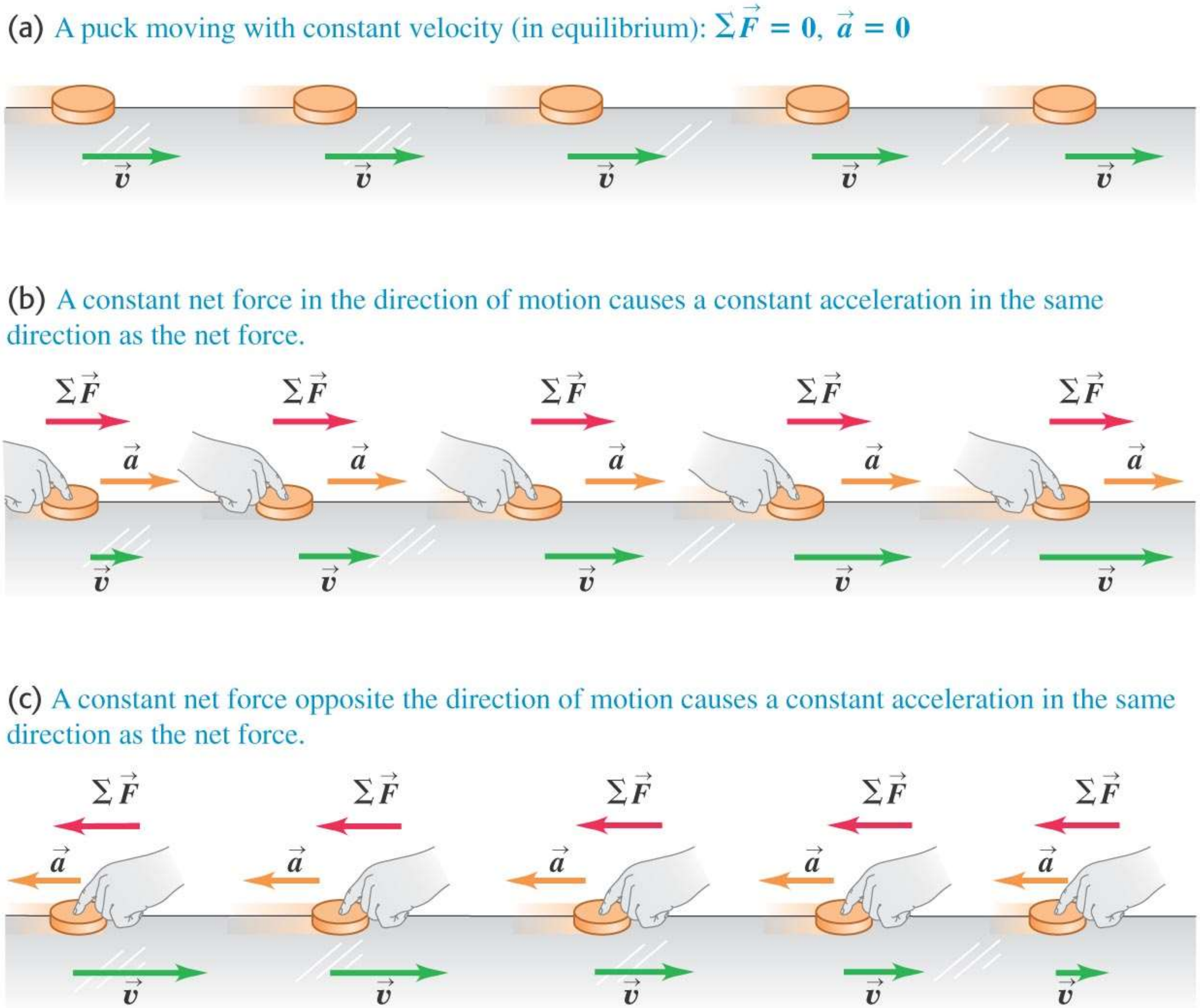
Newton's Second Law

"The acceleration of an object is directly proportional to the net force acting on it and is inversely proportional to its mass. The direction of the acceleration is in the direction of the net force action on the object"

There is a word of caution. This applies to objects described in an inertial frame of reference.

Newton’s Second Law

An unbalanced force (or sum of forces) will cause a mass to accelerate.



Translate: Newton's Second Law

The acceleration is in the SAME direction as the NET FORCE

- → This is a VECTOR equation
  - → It applies for EACH direction
- If I have a NET force, what is my acceleration?
- → More force → more acceleration
- → More mass → less acceleration

Vector Equation :

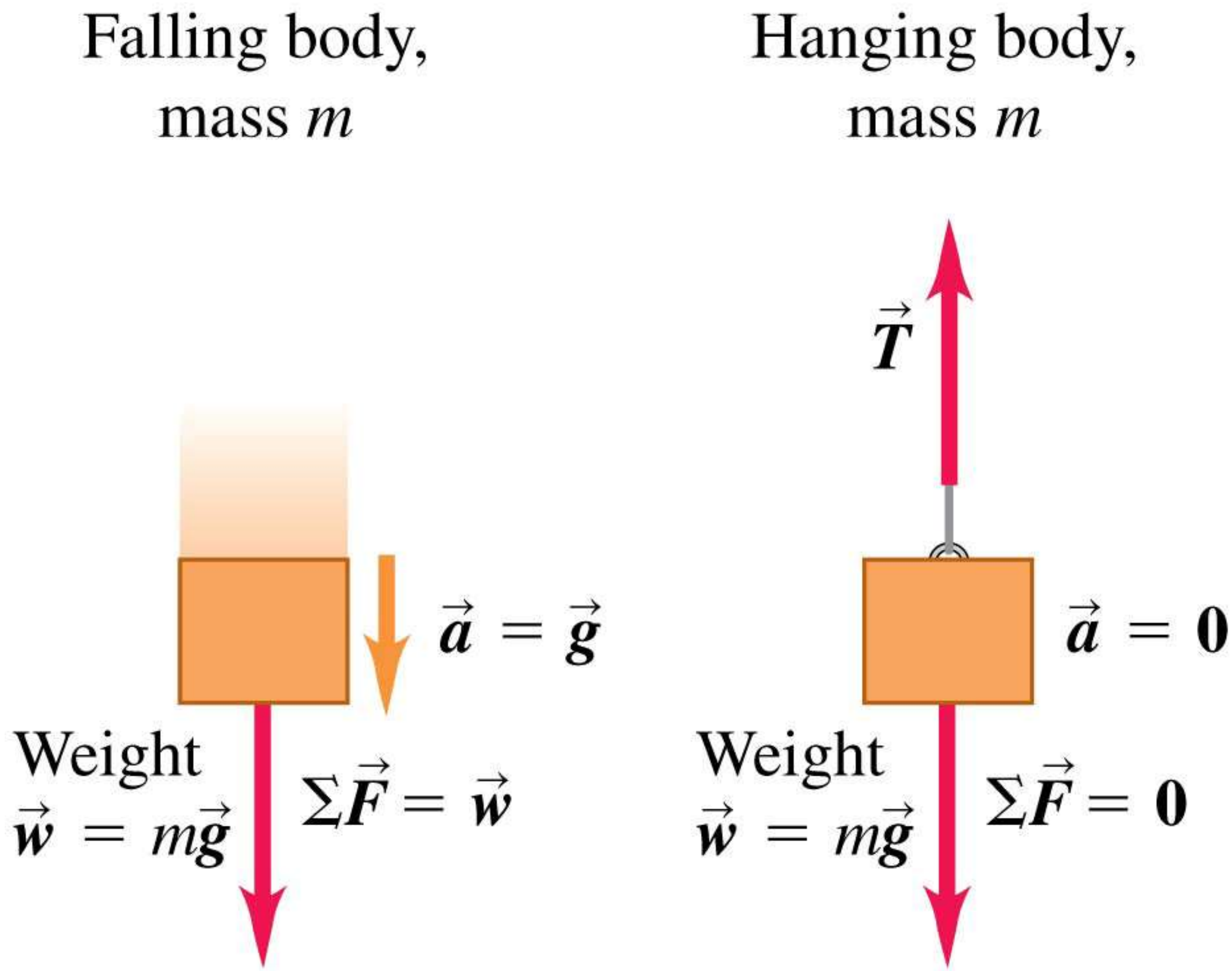
$$\Sigma\vec{F} = m\vec{a}$$

$$\Sigma F_x = ma_x, F_y = ma_y$$

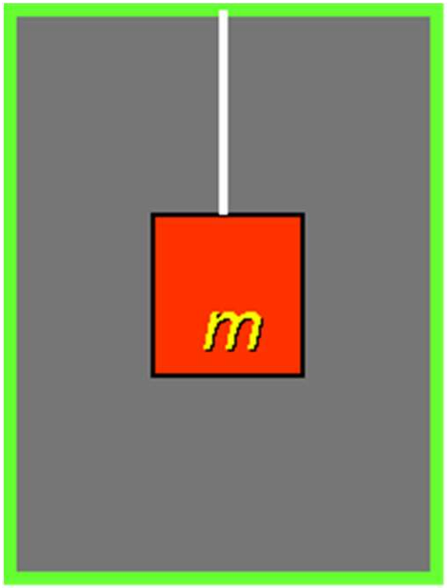
$$\text{Weight} = \vec{W} = m\vec{g}$$

Notice that the 2nd law also implies the 1st law, if **a**=0 then the sum of all forces on an object is zero

Relating the mass and weight of a body



- The relationship of mass to weight: $\vec{w} = m\vec{g}$.
- This relationship is the same whether a body is falling or stationary.



A box of mass m hangs by a string from the ceiling of an elevator that is accelerating upward.

Which of the following best describes the tension T in the string?

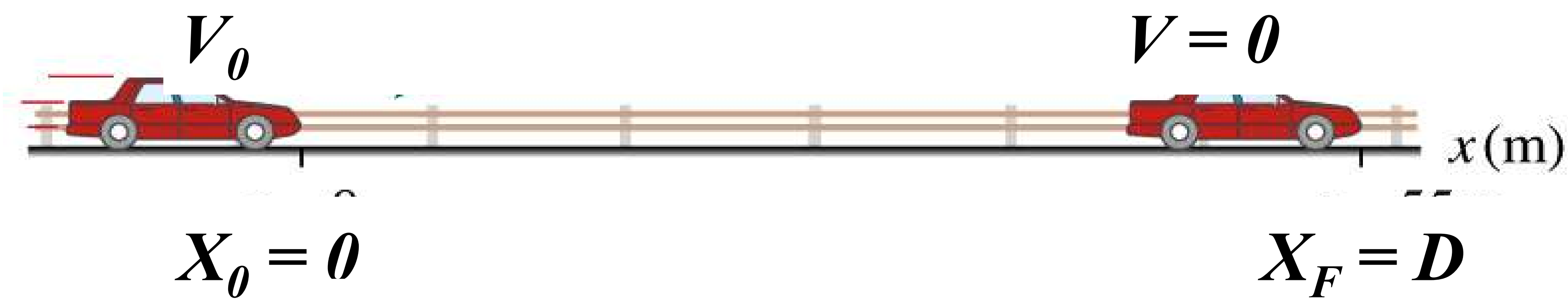
A. $T < mg$

B. $T = mg$

C. $T > mg$

Force to stop a car: combining kinematics and Newtwon's laws

You are a car designer. You must develop a new braking system that provides a constant deceleration. What constant net force is required to bring a car of mass *m* to rest from an speed of V_0 within a distance of *D*?



Strategy: first find the acceleration from kinematics (Ch 2-3) and then connect it to the force via Newton's 2nd law

1st step in kinematic problems

$$x - x_0 = D$$
$$v_0 = v_0$$
$$v = 0$$
$$t =$$
$$a =$$

2nd step in kinematic problems

$$v^2 = v_0^2 + 2a(x - x_0)$$
$$0 = v_0^2 + 2aD$$
$$\Rightarrow a = -\frac{v_0^2}{2D}$$

Connect this result to Newton's 2nd law →

$$F_{net} = ma$$
$$\Rightarrow F_{net} = -\frac{mv_0^2}{2D}$$

Getting to Newton's Third Law

How does one apply a force?

Applying a force requires another object!

- A hammer exerts a force on a nail

Newton's second law applies to EACH object. Newton's 3rd is the one that LINKS these objects

It is the most MISQUOTED of the Newton's laws

Newton's Third Law

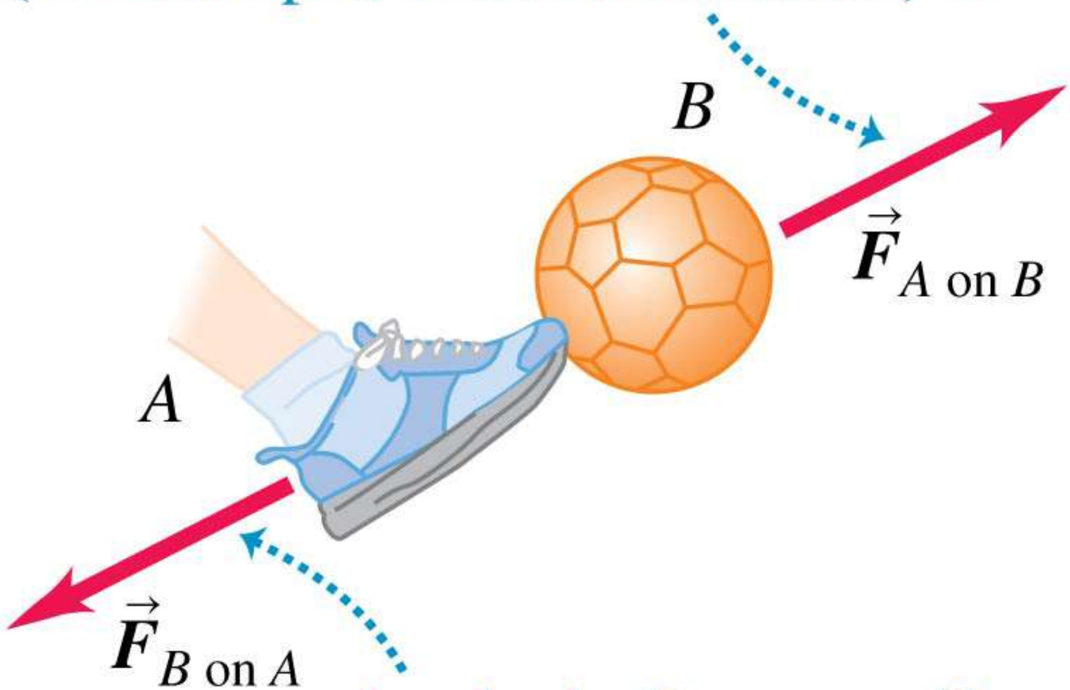
"Whenever one object exerts a force on a second object, the second exerts an equal and opposite force on the first object"

OR

"To every action there is an equal and opposite reaction"

Newton's third law

If body A exerts force $\vec{F}_{A \text{ on } B}$ on body B (for example, a foot kicks a ball) ...

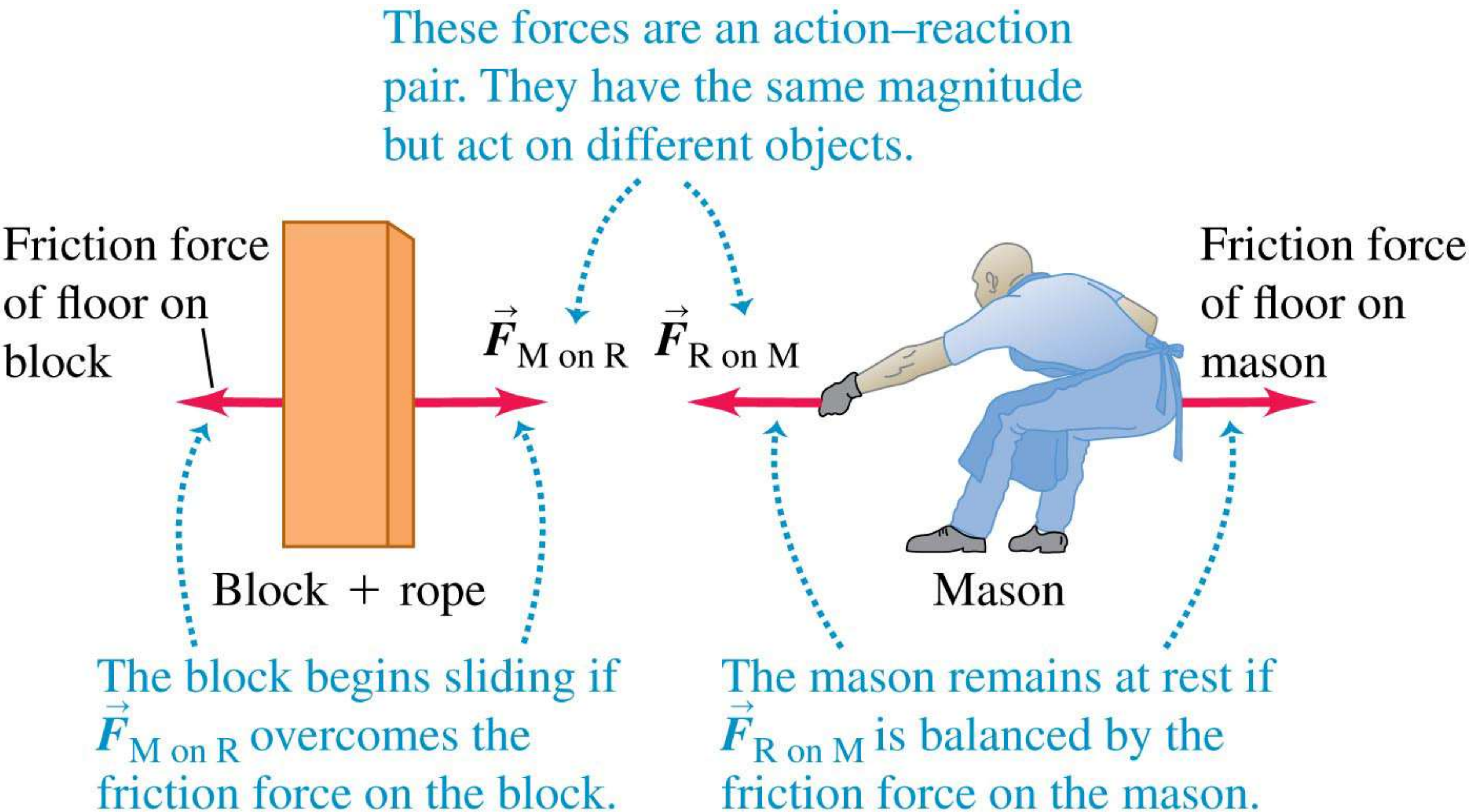


... then body B necessarily exerts force $\vec{F}_{B \text{ on } A}$ on body A (ball kicks back on foot).

The two forces have same magnitude but opposite directions: $\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$.

A paradox?

If an object pulls back on you just as hard as you pull on it, how can it ever accelerate?



Skater

Skater pushes on a wall

The wall pushes back

- Equal and opposite force

The push from the wall is a force

- Force provides an acceleration
- She flies off with some non-zero speed

Walking

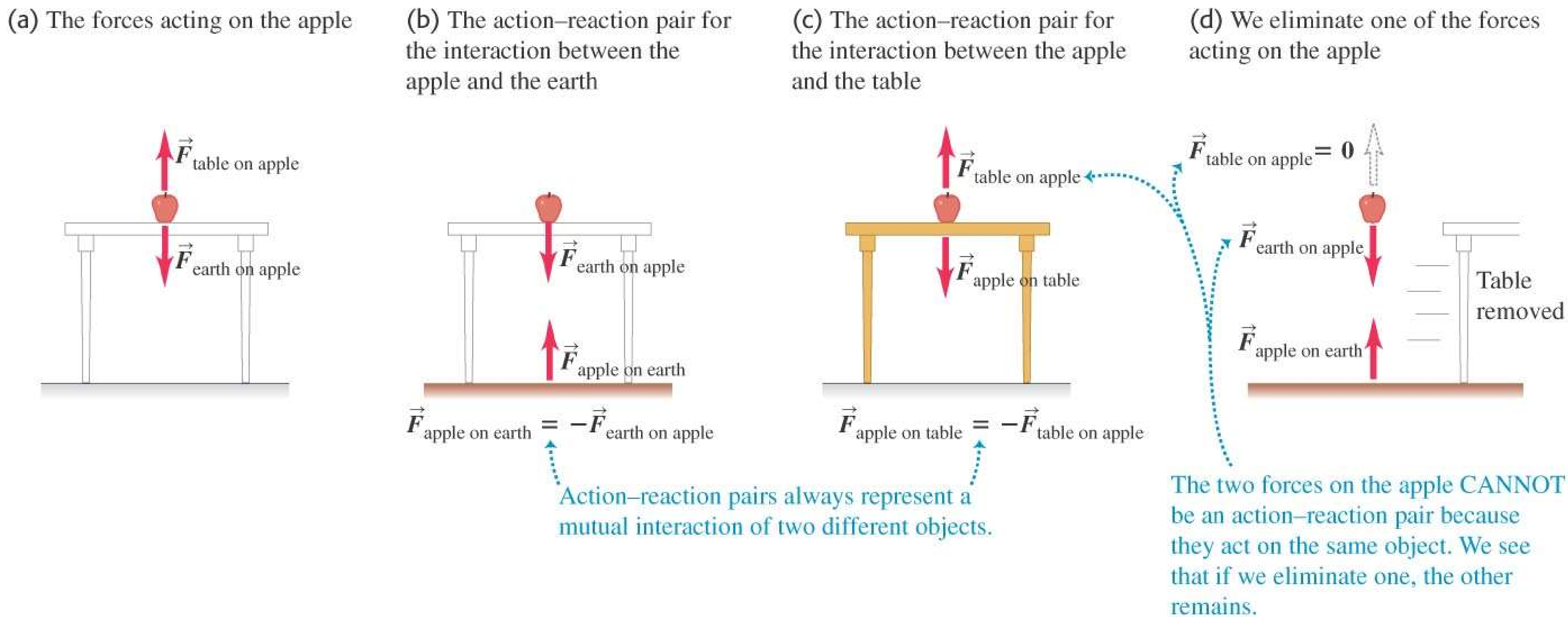
$$\vec{F}_{\text{Ground on the Person}} = -\vec{F}_{\text{Person on the Ground}}$$

She pushes on the ground and the ground PUSHES her forward

Equal and opposite force

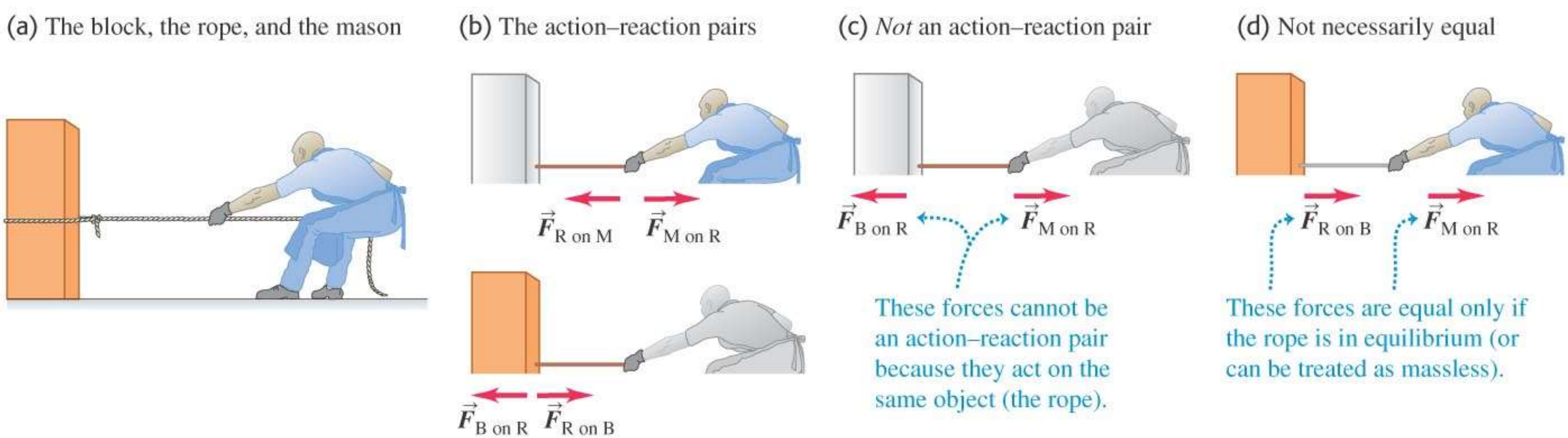
Newton's Third Law—Objects at rest

An apple on a table or a person in a chair—there will be the weight (mass pulled downward by gravity) and the normal force (the table or chair's response).



Newton's Third Law—Objects in motion

An apple falling or a refrigerator that needs to be moved—the second law allows a net force and mass to lead us to the object's acceleration.



Review of Newton's Laws

1st Law: If there *is* an acceleration, there *must be* a net Force

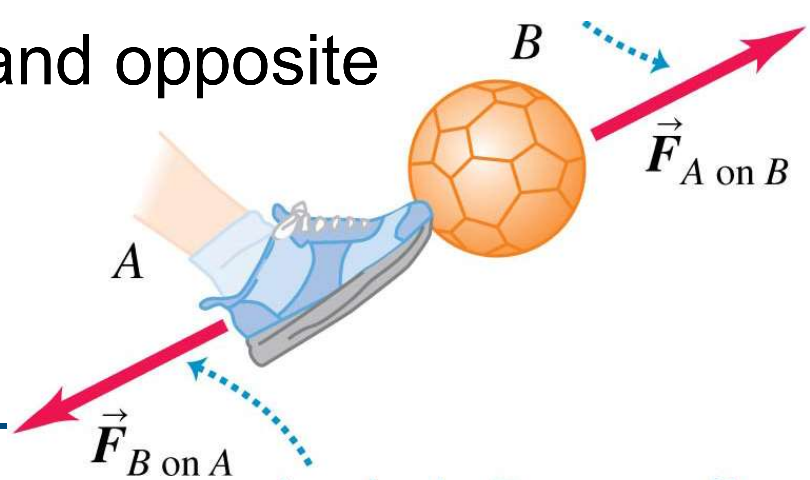
Add up all the forces (vectors) to find the Net (or total) force

2nd Law: *"The acceleration of an object is directly proportional to the net force acting on it and is inversely proportional to its mass. The direction of the acceleration is in the direction of the net force action on the object"*

$\Sigma F = m\, a$, *along each axis*

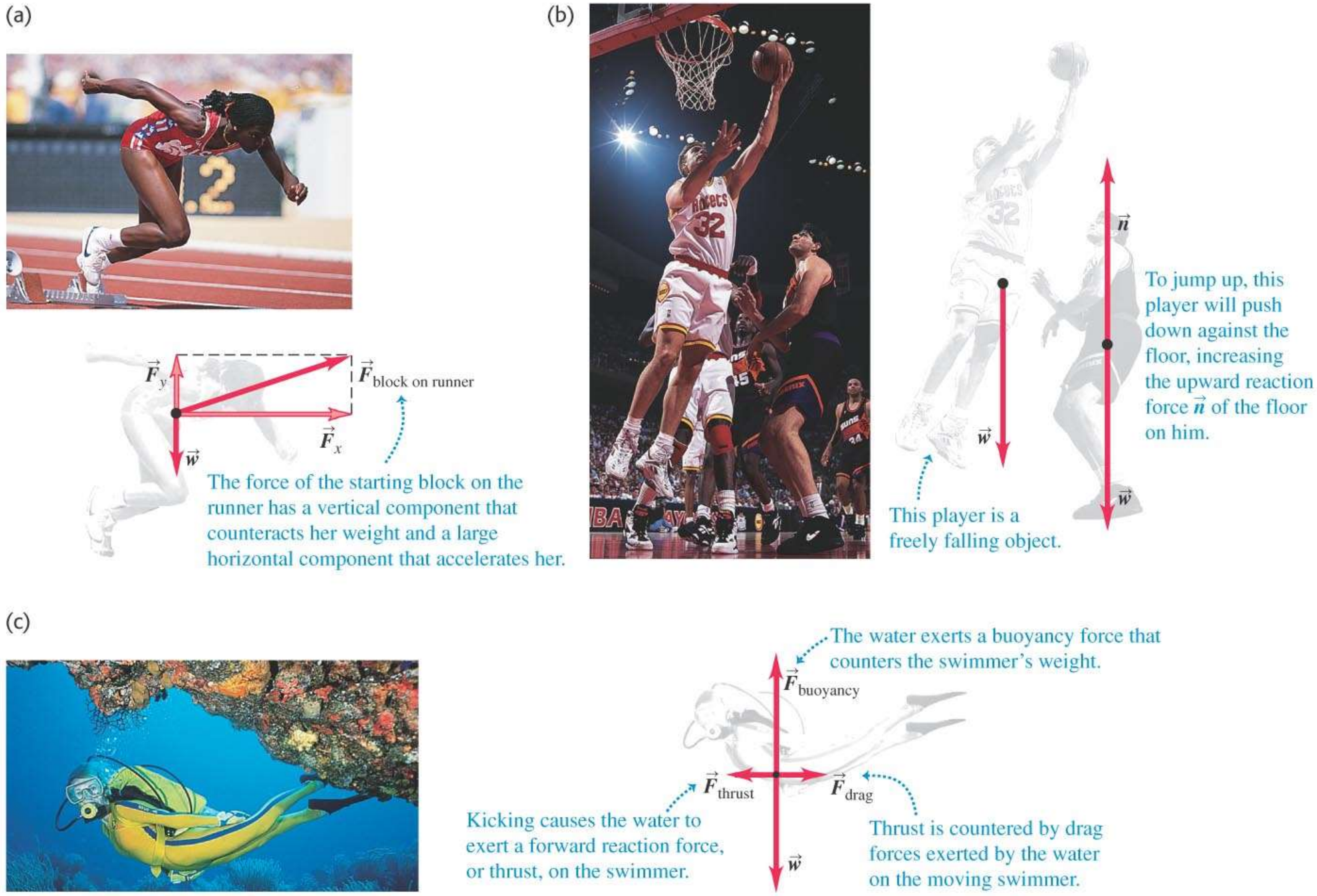
3rd Law: Every action has an equal and opposite reaction.

They act on different objects



Free-body diagrams

A sketch then an accounting of forces



Free Body Diagrams

Same tricks as in Chapters 1-3:

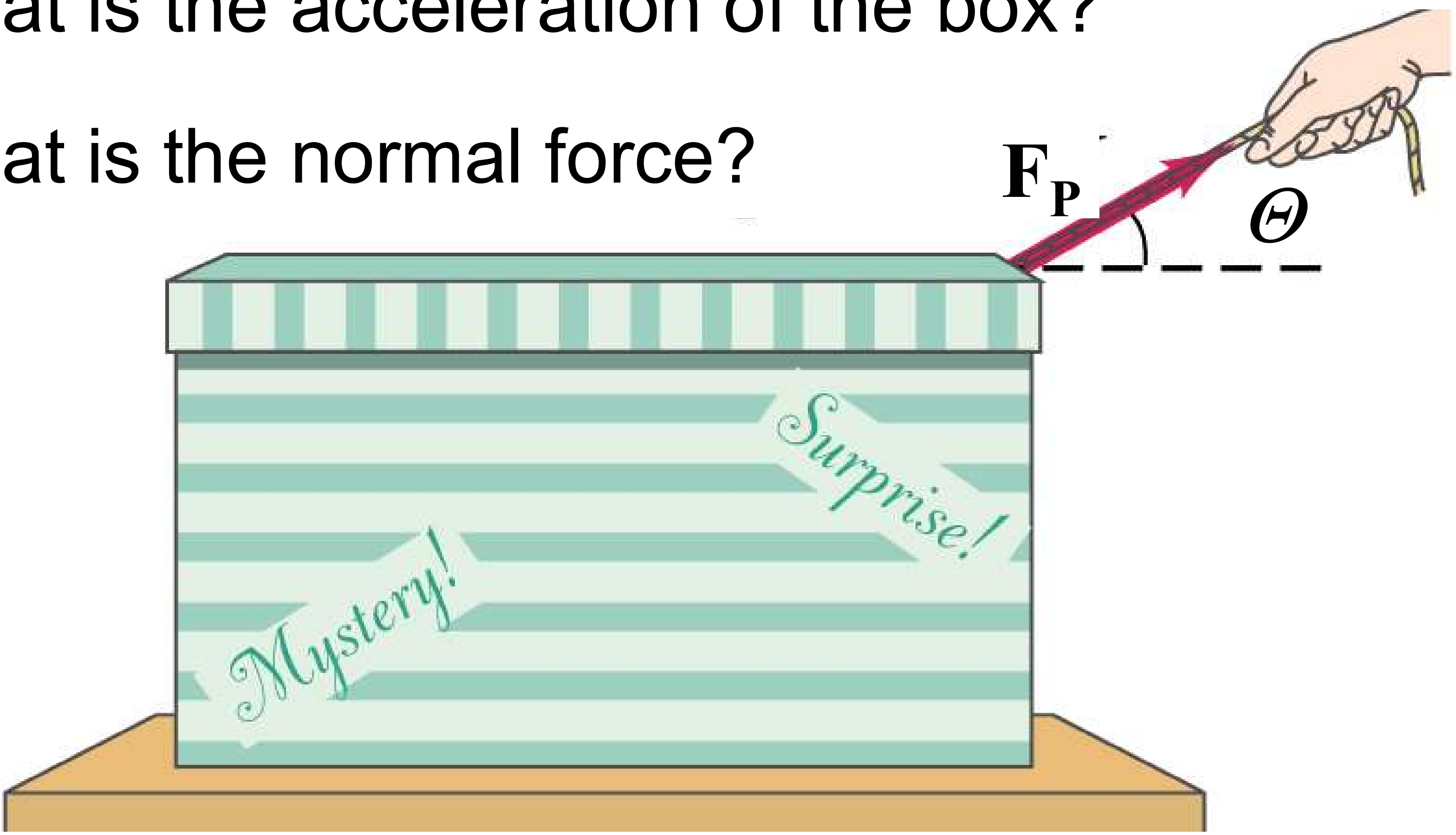
1. Draw a diagram: Draw each force on an object separately! Force diagram!
2. Break each force into the *X* and *Y*-components, THEN sum!!!
   - Show your TA that you know the difference between a force, and a component of force
   - GREAT way to pick up partial credit

Pulling a box

A box with mass *m* is pulled along a frictionless horizontal surface with a force F_P at angle Θ as given in the figure. Assume it does not leave the surface.

a) What is the acceleration of the box?

b) What is the normal force?



2 boxes connected with a string

Two boxes with masses m_1 and m_2 are placed on a frictionless horizontal surface and pulled with a Force F_P. Assume the string between doesn't stretch and is massless.

a) What is the acceleration of the boxes?

b) What is the tension of the strings between the boxes?