Phys101 Lecture 5

Dynamics: Newton's Laws of Motion

Key points:

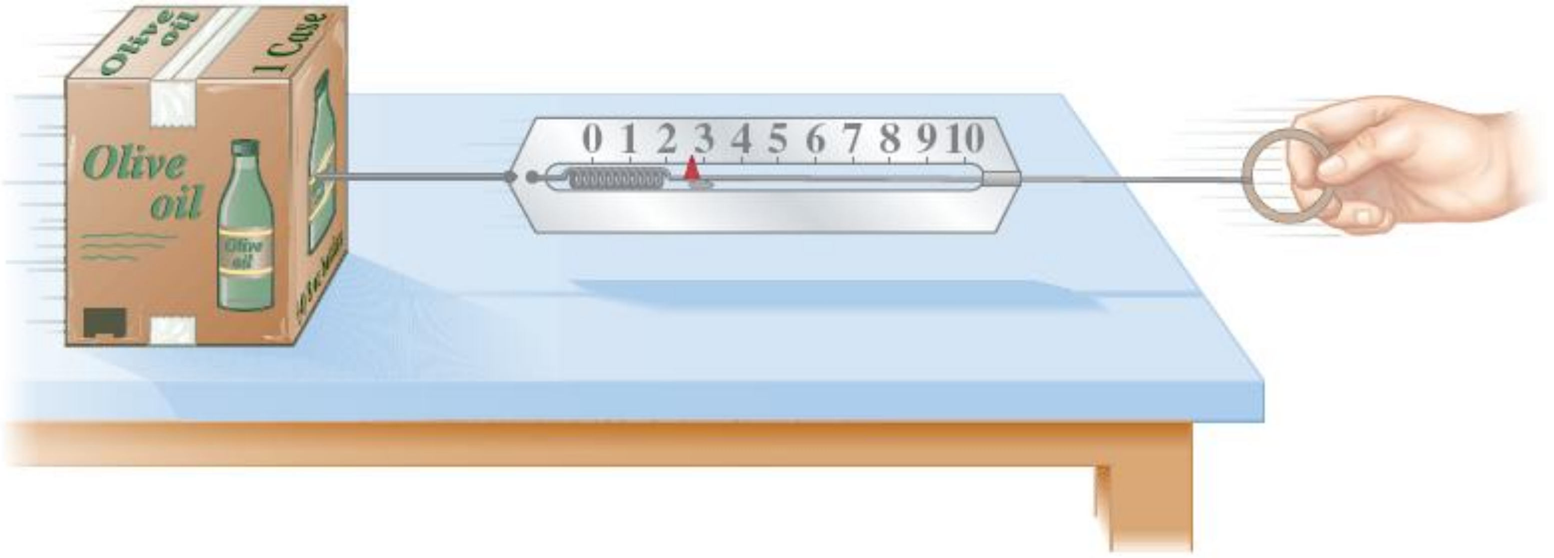
- **Newton's second law is a vector equation**
- **Action and reaction are acting on different objects**
- **Free-Body Diagrams**

Ref: 4-1,2,3,4,5,6,7.

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**.

Force is a vector



Force is a vector, having both **magnitude** and **direction**. The **magnitude** of a force can be measured using a spring scale.

Newton's First Law of Motion

This is Newton's first law, which 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.

Demo: Driving without a seat belt.

Inertial Reference Frames:

Newton's first law does not hold in every reference frame, such as a reference frame that is accelerating or rotating.

An inertial reference frame is one in which Newton's first law is valid. This excludes rotating and accelerating frames.

How can we tell if we are in an inertial reference frame? By checking to see if Newton's first law holds!

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.

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

It takes a force to change either the direction or the velocity of an object. i.e., force is the cause of change of motion.

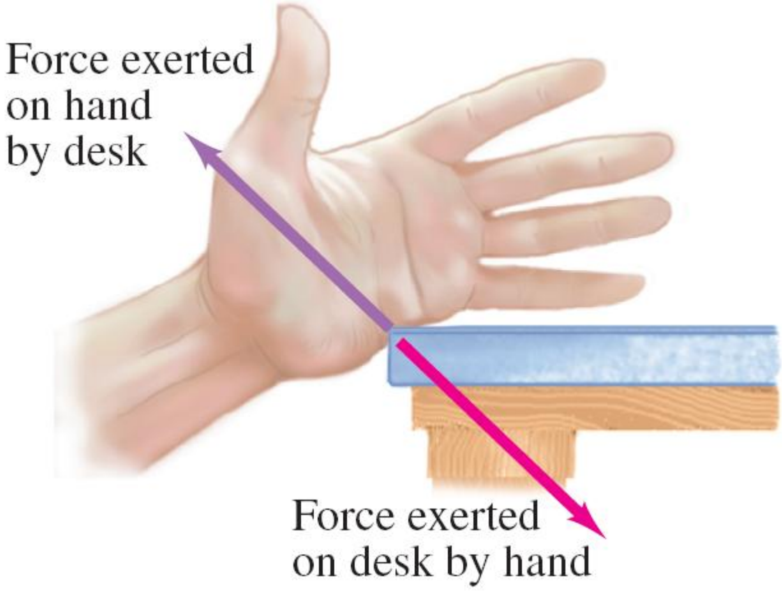
Note:

If we know the mass of an object and the net force acting on it, we will know its acceleration, but not the velocity (we don't know how fast the object moves unless we have additional information).

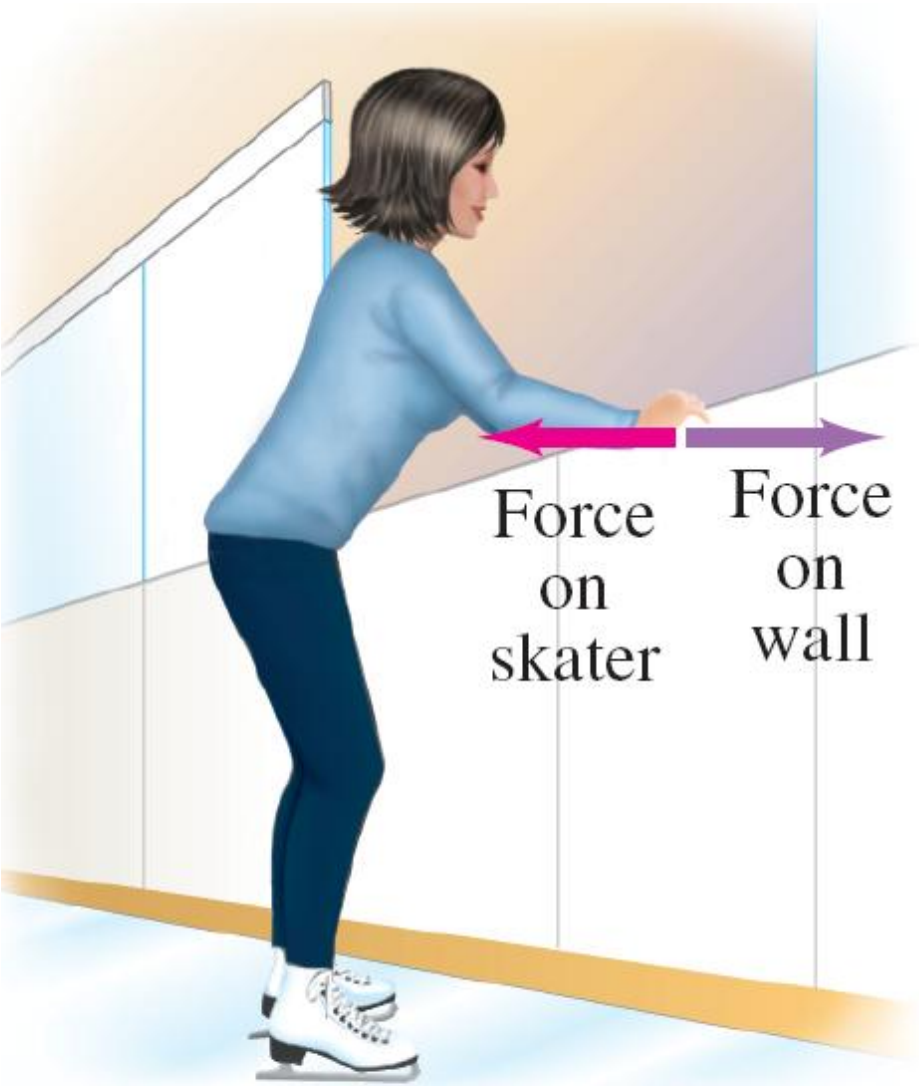
Newton's Third Law of Motion

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.



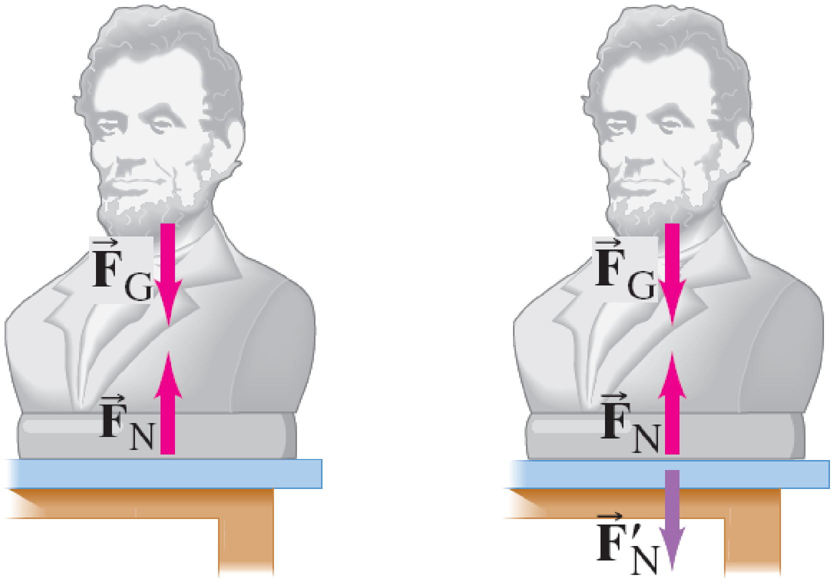
Newton's Third Law of Motion



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.

The Normal Force

The force exerted perpendicular to a surface is called the normal force.



i-clicker question 5-1

A block of mass *m* rests on the floor of an elevator that is moving upward at constant speed. What is the relationship between the force due to gravity and the normal force on the block?

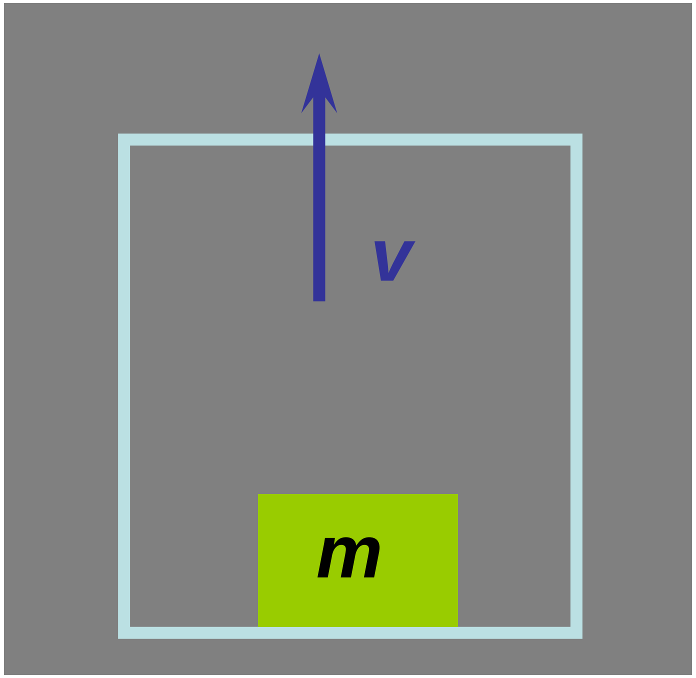
A. 1) $N > mg$

B. 2) $N = mg$

C. 3) $N < mg$ (but not zero)

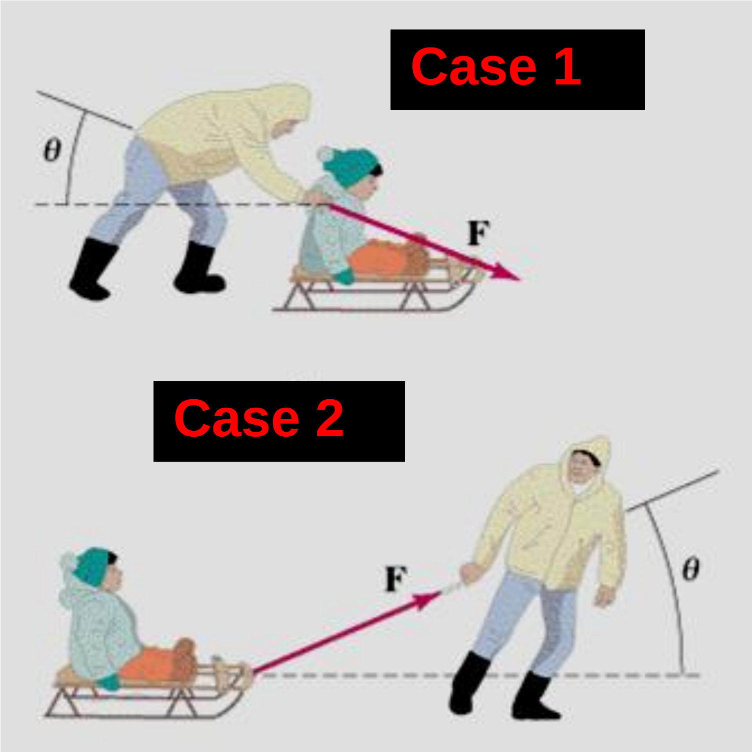
D. 4) $N = 0$

E. 5) depends on the size of the elevator



i-clicker question 5-2

Here you see two cases: a physics student pulling or pushing a sled with a force *F* that is applied at an angle θ. In which case is the normal force greater?



A) case 1

B) case 2

C) it's the same for both

D) depends on the magnitude of the force *F*

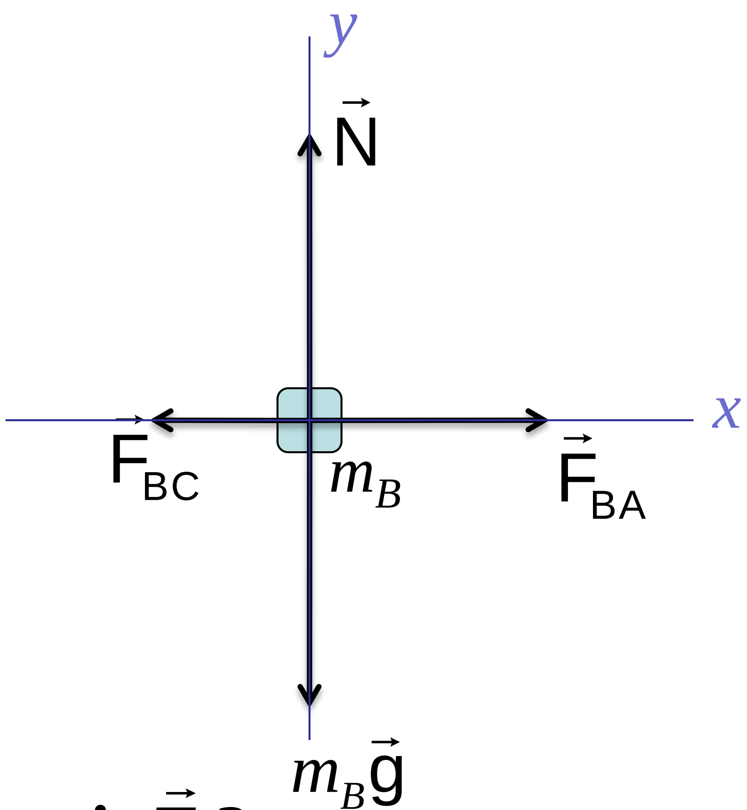
E) depends on the ice surface

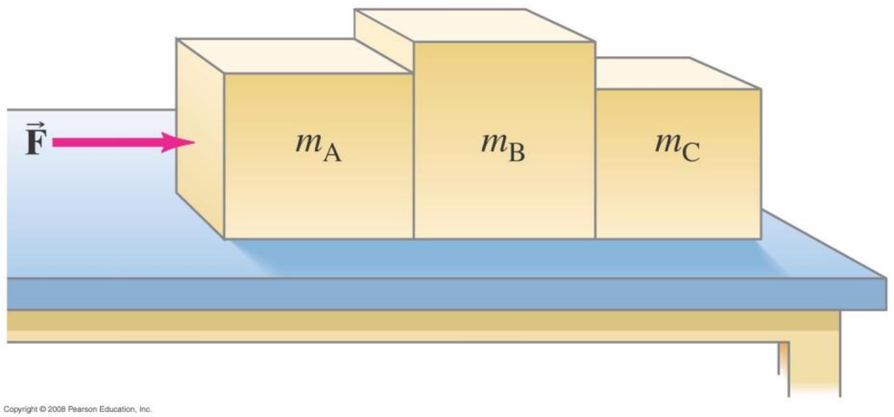
Free-Body Diagram

A diagram showing all forces acting ***on*** an object.

What does "free-body" mean? Isolate the object.

Example: Draw a FBD for object m_B (assume no friction)





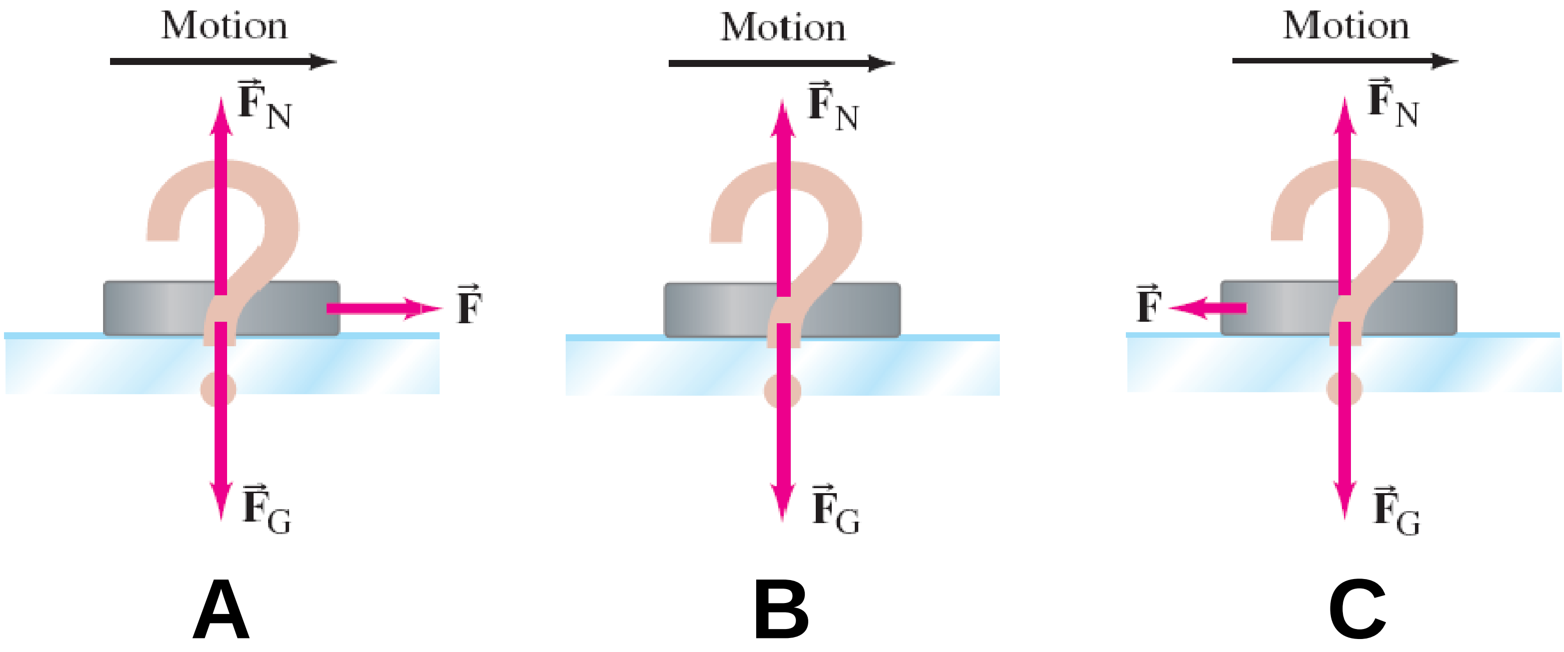
Set up your coordinate system for components.

There are two kinds of forces:

1. **Contact forces**
2. **Field forces (gravity, electric, etc)**

Where is $\vec{F}$?

i-clicker question 5-3 and 5-4

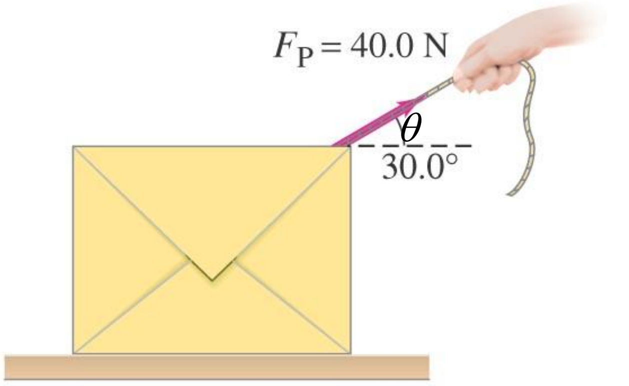


Conceptual Example 4-10: The hockey puck.

A hockey puck is sliding at constant velocity across a flat horizontal ice surface that is assumed to be frictionless. Which of these sketches is the correct free-body diagram for this puck? What would your answer be if the puck slowed down?

Example 4-11:

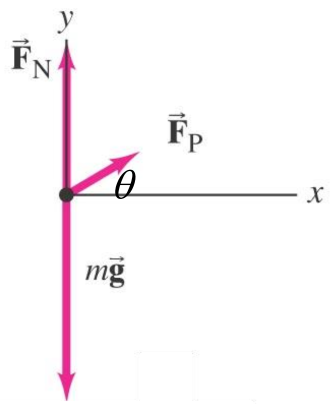
Tim pulls a 10-kg box by an attached cord on the smooth surface of a table. The magnitude of the force exerted by Tim is F_P = 40.0 N, and it is exerted at a 30.0° angle as shown. Calculate the acceleration of the box.



Free-body diagram:

contact forces: Pull by Tim;
Normal force.

Field forces: Gravity



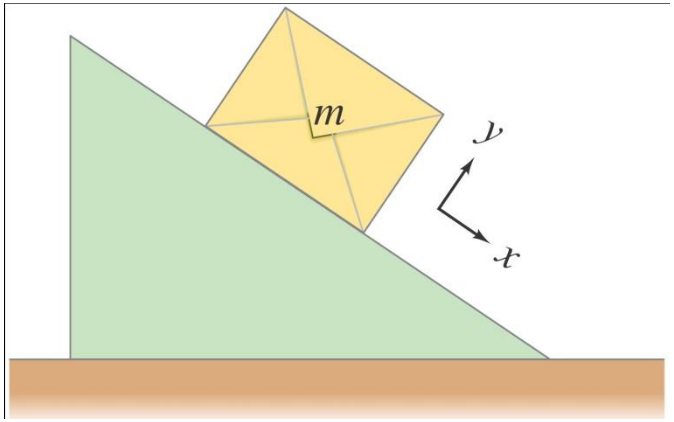
$$\text{Newton's Law}: \ \vec{F} = m\vec{a}$$

$$x\text{-component}: \ F_p \cos\theta = ma_x$$

$$y\text{-component}: \ F_N + F_P \sin\theta - mg = 0$$

$$\text{Solve for } a_x: \qquad a_x = \frac{F_p \cos\theta}{m} = \frac{(40.0)(\cos 30°)}{10.0} = 3.46 m/s^2$$

Example 4-16: Box slides down an incline.



A box of mass *m* is placed on a smooth incline that makes an angle θ with the horizontal. (a) Determine the normal force on the box. (b) Determine the box's acceleration. (c) Evaluate for a mass *m* = 10 kg and an incline of θ = 30°.

[Solution]

First, FBD and x-y coordinates.

Then, Newton's law in component form:

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

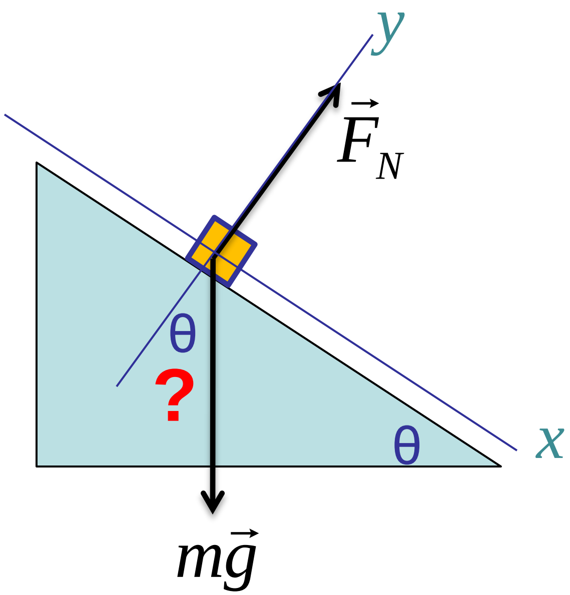
$$x\text{-comp:} \quad mg\sin\theta = ma_x$$

$$y\text{-comp:} \quad F_N - mg\cos\theta = 0$$

(a) $F_N = mg\cos\theta$

(b) $a = a_x = g\sin\theta$

(c) $F_N = 85N, \quad a = 4.9m/s^2.$

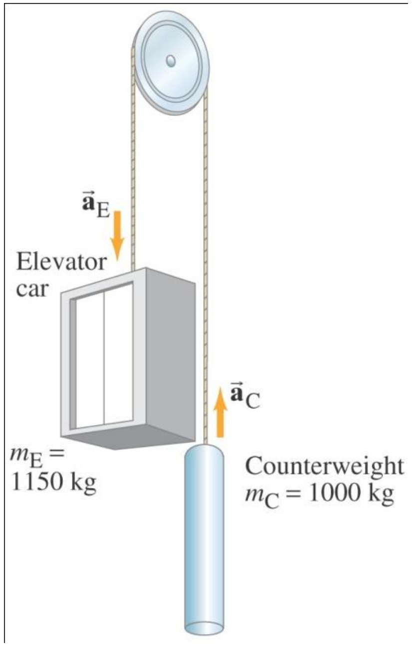


Again, two kinds of forces:

1. **Contact forces**
2. **Gravity.**

Example 4-13: Elevator and counterweight (Atwood's machine).

The mass of the counterweight is 1000 kg. The total mass of the elevator with passengers is 1150 kg. Calculate (a) the acceleration of the elevator and (b) the tension in the cable. Ignore the mass of cable and friction.



[Solution] For each object, we need to draw a FBD and apply Newton's law.

Ignoring friction and cable mass means the same tension in cables on both sides of pulley. ?

Kinematics relation: $a_{Cy} = -a_{Ey} = a$

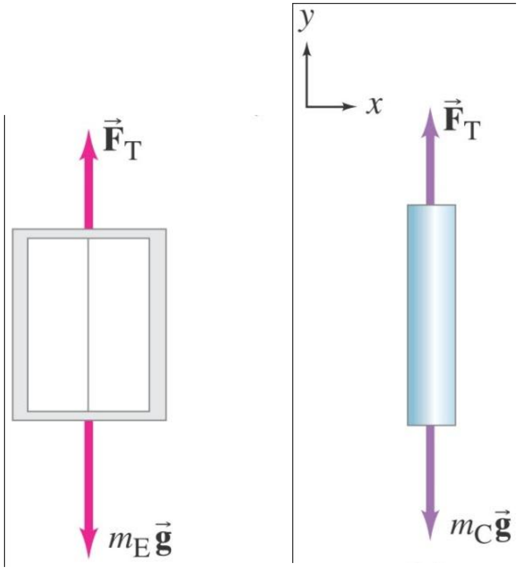
$$F_T - m_C g = m_C a_{Cy} = m_C a$$

$$F_T - m_E g = m_E a_{Ey} = -m_E a$$

Solve for a and F_T :

$$a = \frac{m_E - m_C}{m_E + m_C} g = 0.68 m/s^2$$

$$F_T = m_C(a + g) = 10500 N$$



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: $\vec{\mathbf{F}}_{\mathrm{AB}} = -\vec{\mathbf{F}}_{\mathrm{BA}}.$

• Weight is the gravitational force on an object.

• Free-body diagrams are essential for problem-solving. Do one object at a time, make sure you have all the forces, pick a coordinate system and find the force components, and apply Newton's second law along each axis.