

Physics 221

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Newton's Laws – Part 1 Forces and Motion

Announcements

- Read Chapter 5 to the end. We will finish it Monday, and the problems will be due Wednesday.
- Problem set 5 is posted and due Wednesday. The problems are from Chapter 5:
3, 17, 20, 28, 29, 40, 43, 57.
- The exams are not graded yet. I expect to return them Wednesday, when we have the next problem discussion.
- Don't panic: partial credit is awarded liberally.

What is a Force?

- Forces model interactions, interactions always occur in pairs (action – reaction), forces add as vectors (experimental fact, required for model, not proven by it). Some forces are more fundamental than others.
- Physicists recognize four fundamental forces: gravity, electricity + magnetism (unified by Einstein), and the strong and weak nuclear forces.
- The forces we experience come in two categories: contact forces, and forces at a distance. Contact forces really are the result of electricity in most cases: the repulsion of electrons in atoms.

Newton's First Law

- A reference frame refers to a coordinate system tied to an observer, in which the positions and velocities of particles can be measured.
- Usually, we think of reference frames as being at rest, but they don't have to be: they could be tied to some moving object.
- This is usually the case: after all, the earth moves! So does the sun... and the galaxy, etc. The whole universe is expanding.

Newton's First Law

- If an object does not interact with any other object, there exist reference frames in which the object has zero acceleration.
- Such a reference frame is called an **inertial frame**.
- In an inertial frame, an isolated object moves with a constant velocity.
- Any frame moving at a constant velocity with respect to an inertial frame is also inertial.

Newton's 2nd Law

- A non-interacting object experiences no acceleration and feels no forces.
- If an object interacts, it feels forces, which influence its motion.
- How much the motion is influenced by the forces depends on the object's **mass**, which is a measure of its inertia, or resistance to acceleration.

Newton's 2nd Law

- Forces act as vectors. If the vector sum of forces on an object is zero, the object experiences no acceleration.
- If the total force vector acting on an object is \vec{F} , then the acceleration of the object is determined by the net force and the object's mass:

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

Surfer

You are surfing a large wave, maintaining a constant height on the leading edge of the wave while it carries you to shore at a steady speed. The net force on you is

- A. uphill – toward the crest behind you.
- B. downhill – toward the trough in front of you.
- C. zero.
- D. horizontal – toward the shore.

Newton I: Constant velocity implies zero net force.

Units, Weight

Added in response to questions asked in both classes

Force is measured in Newtons, a *derived* unit.

$$1 \text{ N} = F = ma = 1 \text{ kg m/s}^2$$

- Weights are forces, and can be given in units of Newtons or pounds. It is incorrect to measure weights in kg, because this is a mass, not a force.
- 1 kg *weighs* 2.2 lb on earth, but this would be different elsewhere. The mass of an object is a property of the object, and doesn't change on other planets.

Weight

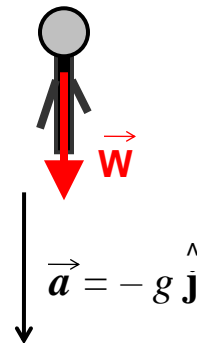
Weight is the force of gravity.

We know that objects near earth fall with acceleration $g = 9.8 \text{ m/s}^2$ if acted on by gravity alone.

This means that

$$W = mg.$$

A 100 kg person has weight 980 N.

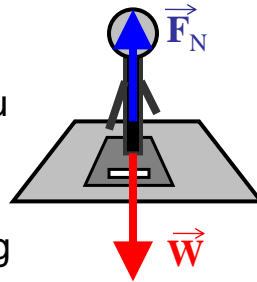


Weight and Normal Force

If you are standing on a floor, the floor pushes up on you with a force opposite your weight to prevent you from falling.

This contact force is called the **normal force**, with normal meaning perpendicular, since it is perpendicular to the floor.

If you are standing on a scale, the scale measures the contact force between you and the scale, F_N , and thus, indirectly, your weight W .



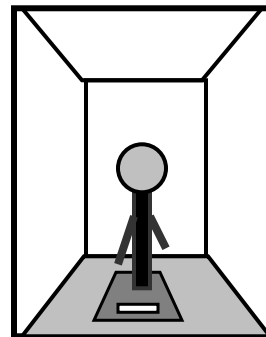
$$\vec{F}_N + \vec{W} = 0$$

Weight in an Elevator

An elevator accelerates upward at 2.2 m/s^2 .

What does the passenger apparently weigh, as measured by the scale in the elevator, if his mass is 100 kg ?

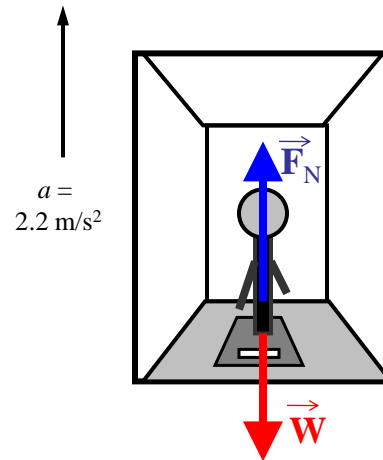
$a = 2.2 \text{ m/s}^2$



Weight in an Elevator

The scale measures the contact force on the passenger. This is called the **normal force**, since it is perpendicular to the ground.

If the elevator were at rest, the weight and normal force would balance.

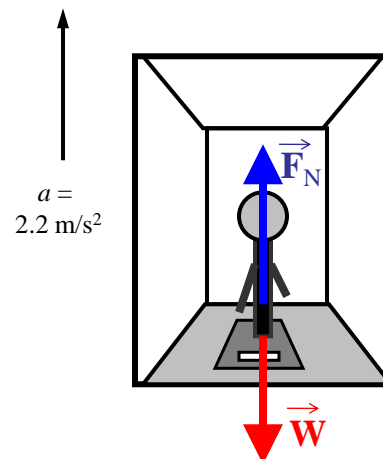


Weight in an Elevator

But the elevator is accelerating - there is a net force on the passenger: it is $F_N - W$.

Newton's law:

- $F_N - W = ma$.
- $W = mg$.
- $F_N = ma + mg = m(a+g)$
 $= (100 \text{ kg})(12.0 \text{ m/s}^2)$
 $= 1200 \text{ N}$.



Unit Conversion

What is the apparent weight in pounds?

Multiply by conversion factor in such a way that the unwanted units cancel.

1 kg **weighs** $mg = 9.8 \text{ N} = 2.2 \text{ lb}$. Therefore, the conversion factor from Newtons to pounds is $9.8 \text{ N}/2.2 \text{ lb} = 4.45 \text{ N/lb}$.

Apparent weight $F_N = 1200 \text{ N} / (4.45 \text{ N/lb})$
 $= 270 \text{ lb}$.

Newton's Third Law

- All interactions occur in pairs.
- If object 1 acts on object 2 with a force \vec{F}_{12} , then object 2 acts on object 1 with a force \vec{F}_{21} .
- The forces due to these interactions are related:

$$\vec{F}_{12} = -\vec{F}_{21}$$

Rocket at Rest

A rocket on earth is at rest.

Gravity is pulling down on the rocket with the weight of the rocket. With what force does the rocket pull on the Earth?

The rocket pulls up on the earth with a force equal to its weight.

Rocket at Rest

A rocket on earth is at rest.

What is the net force on the rocket?

The net force is zero. What force balances it.

It can't be the force of the rocket on the earth: that acts on a different object. We need a force acting on the rocket.

The contact force, or normal force, of the earth pushing on the rocket balances its weight.

Rocket in Motion

As the rocket takes off, it accelerates upward. What is the force of the earth on the rocket now?

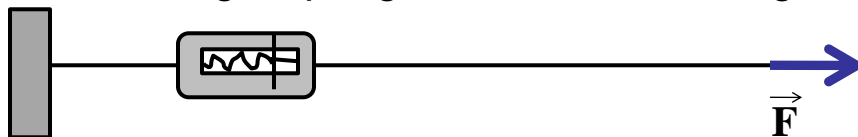
- It is still the weight of the rocket, but the rocket engines produce thrust that exceeds its weight, allowing it to accelerate upward.

What is the force of the rocket on the earth now?

- Again, it is the weight of the rocket.

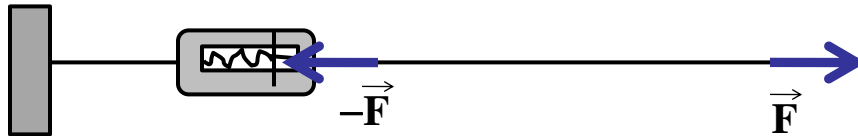
Tension

- When you pull on a string, you apply a force to it. This force is called the **tension**.
- If the string is perfectly flexible, the tension always acts along the direction of the string.
- You could measure the tension by attaching a spring balance to the string.



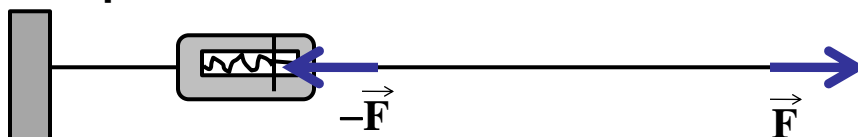
Tension

- If the force pulling on the right is \vec{F} , then the tension in the string is F .
- If the string is at rest, the net force on it is zero.
- The spring balance is pulling to the left with the force $-\vec{F}$.



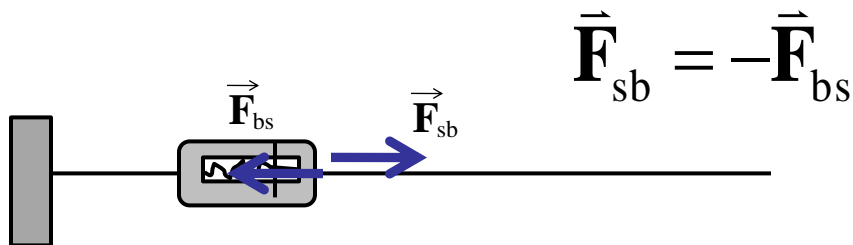
Tension

- Are the two forces shown in the figure an action-reaction pair?
- No: they both act on the same object: the string. They balance only because the string is not accelerating.
- Balanced forces are said to be in **equilibrium**.



Tension

- The force of the balance on the spring and the force of the spring on the balance are an action-reaction pair. These are always opposite, regardless of whether the string is accelerating or in equilibrium.



Pulleys

- Pulleys can be used to redirect tension. Tension always follows the string.
- If the pulley exerts only a normal force on the string at any contact point, it is said to be **frictionless**. If the pulley is massless or stationary, then the magnitude of the tension is the same on both sides.

