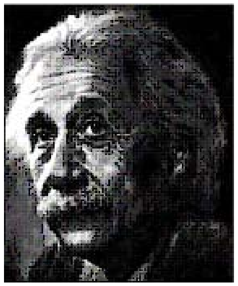
# Force, Motion, and Sound

*Physics 160, Spring 2006*



Galileo (1564-1642)

Isaac Newton (1643-1727)

# Uniform Motion

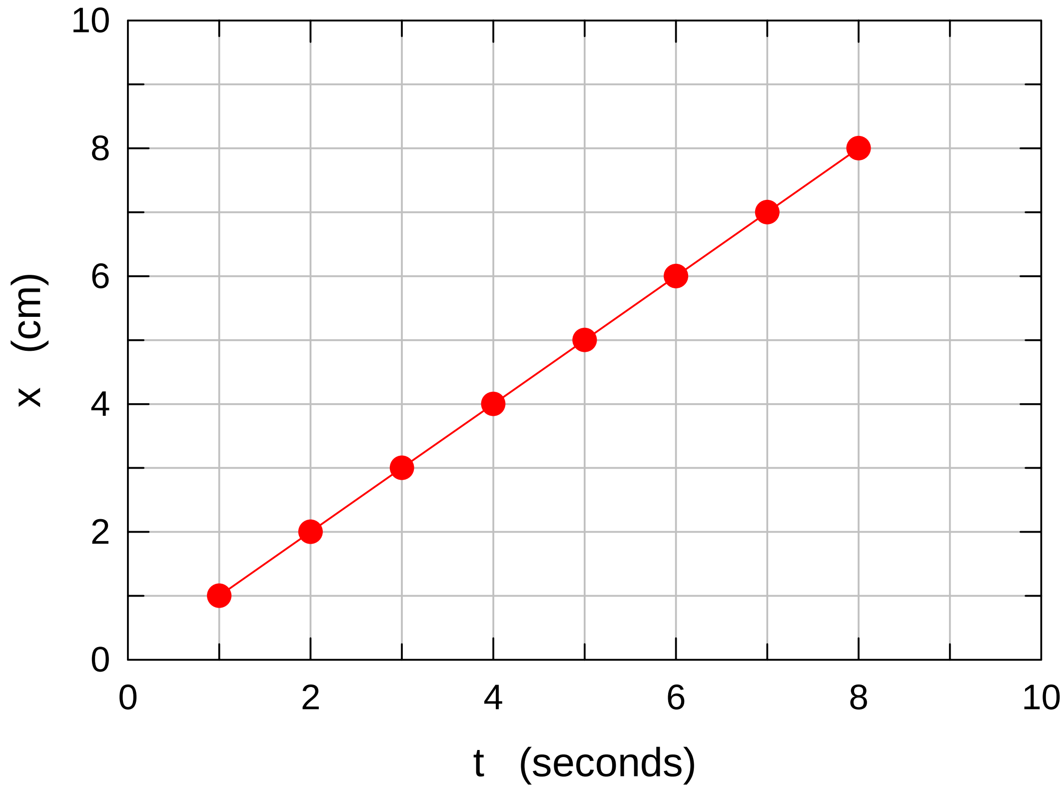
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| x = | 1cm | 2cm | 3cm | 4cm | 5cm | 6cm | 7cm | 8cm |
| O • | • | • | • | • | • | • | • | • |
| t = | 1s | 2s | 3s | 4s | 5s | 6s | 7s | 8s |

This picture shows the location of an object at successive times (1 second intervals). Note that in each second, the object moves 1 cm. Its speed is therefore 1 cm/s and is constant.

An object moving in a straight line, in one direction, with constant speed has "*constant velocity*" and is said to be in "uniform motion".

You can calculate the speed of an object with constant velocity by taking *any* two points on the path and dividing the distance between them by the time duration between them.

# Graph for Uniform Motion




In a graph of position vs. time, constant velocity gives a straight line: the steeper the line, the faster the motion.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| x = | 1cm | 2cm | 3cm | 4cm | 5cm | 6cm | 7cm | 8cm |
| O ● | | | | | | | | |
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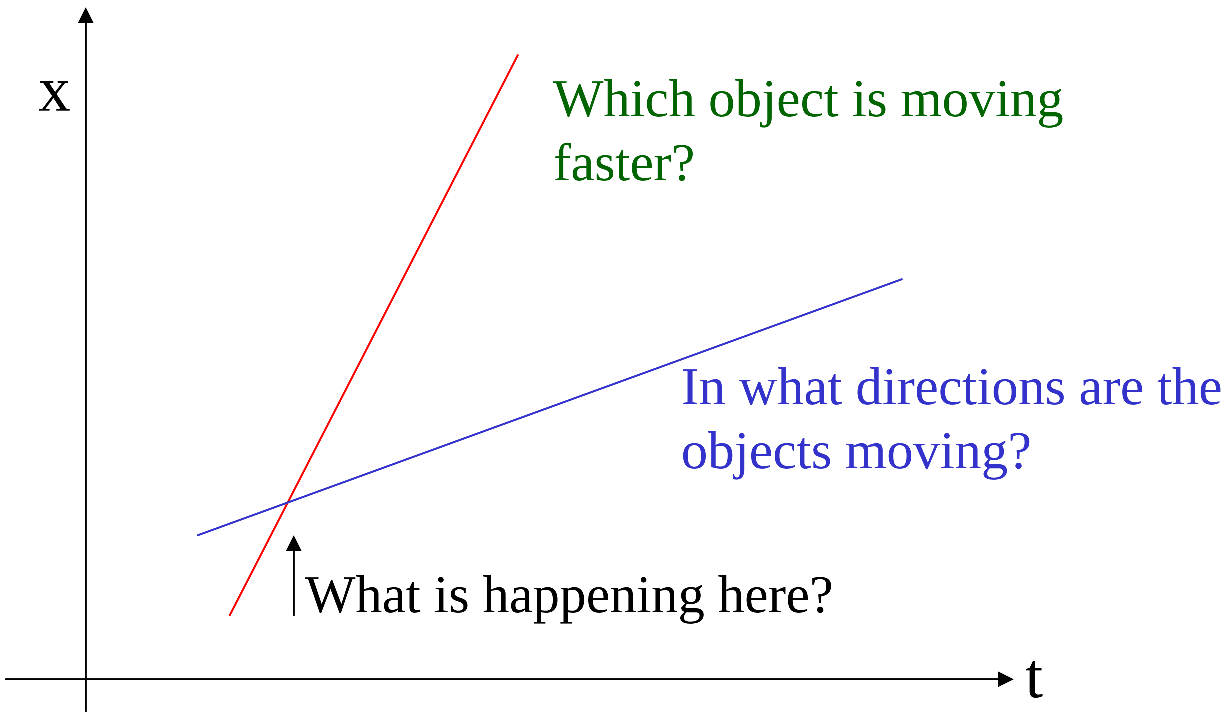
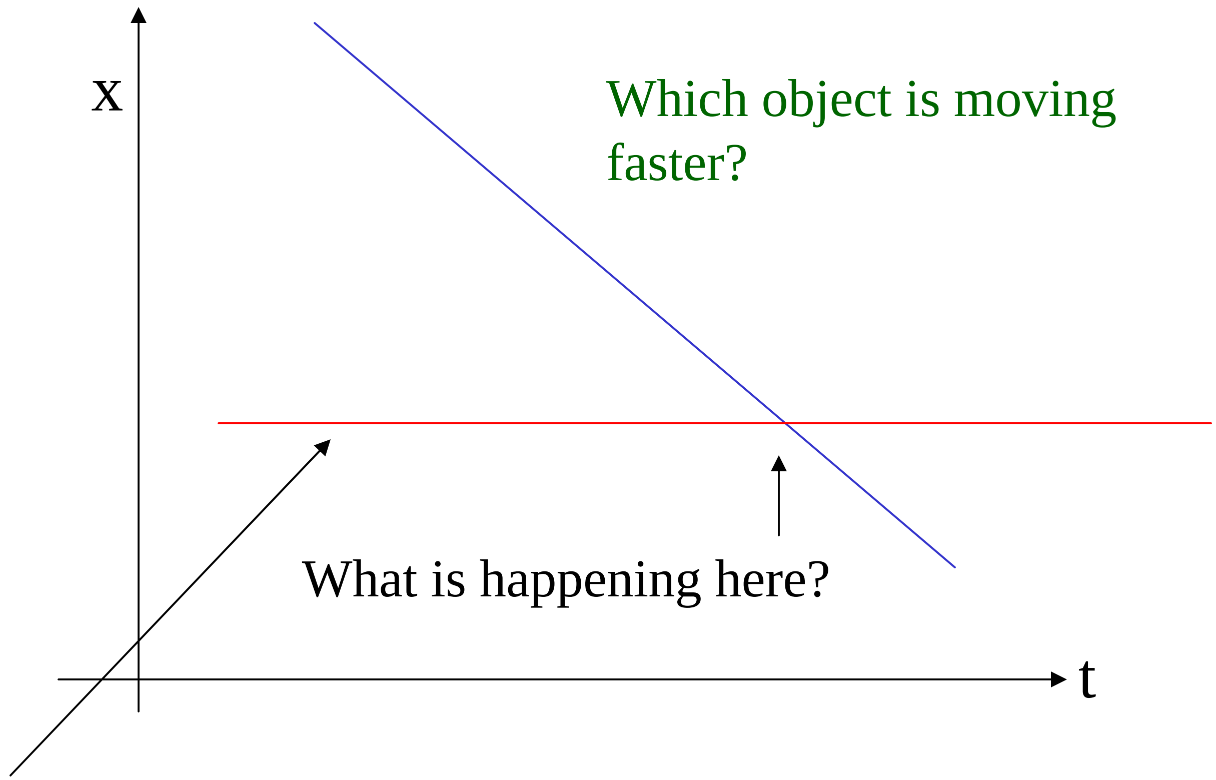
# Graph for Uniform Motion




Graph for uniform motion is a straight line.

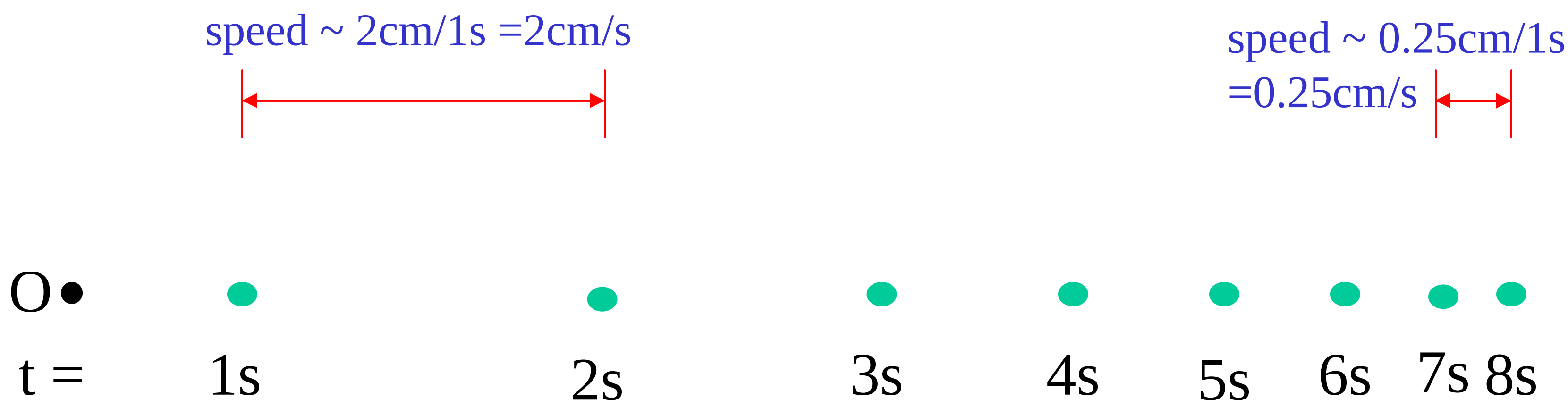
"Steepness" or slope gives the speed of the motion.

## Graph for Uniform Motion



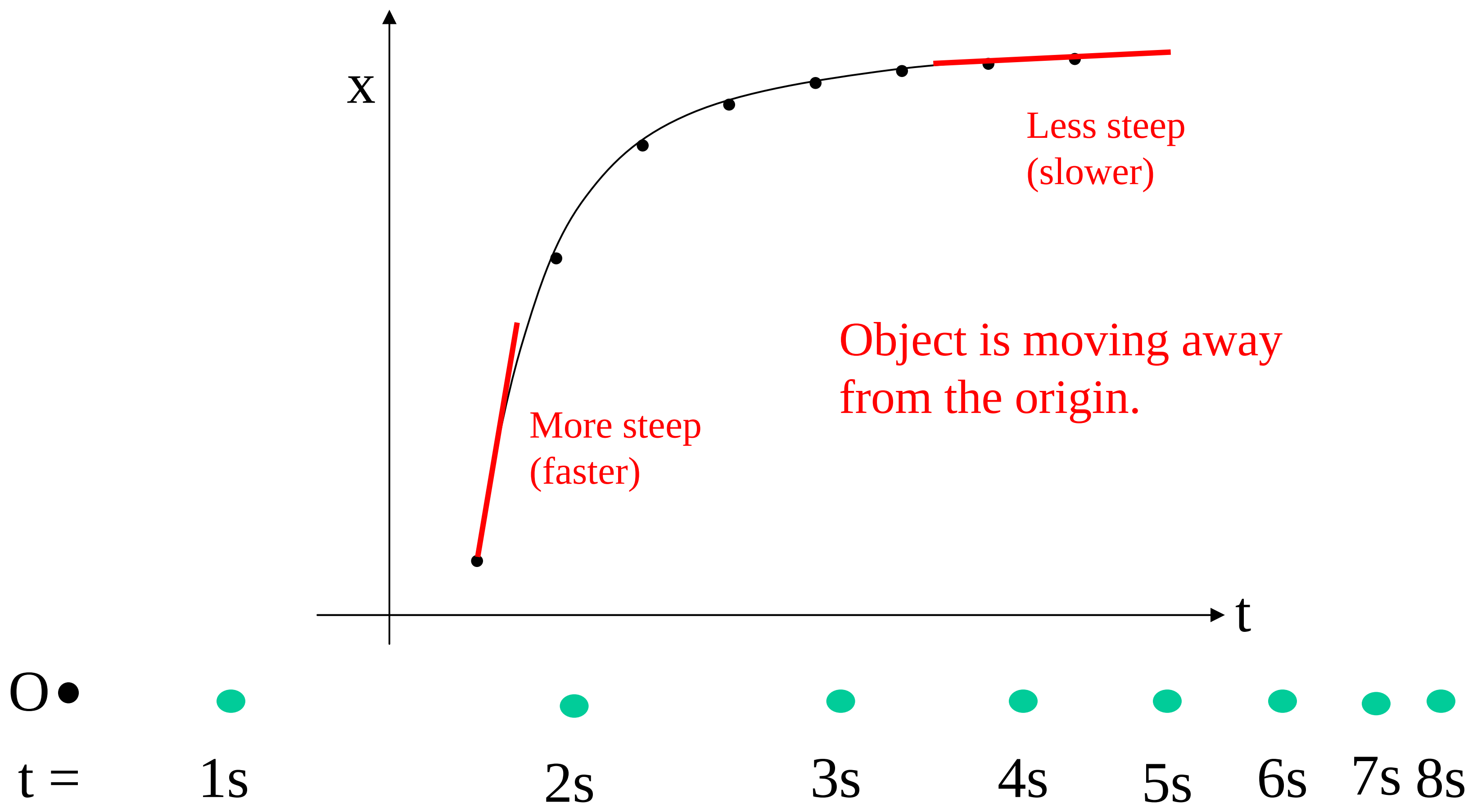

“Not moving” is a particular case of uniform motion, with speed =0.

## Non-uniform Motion - slowing down

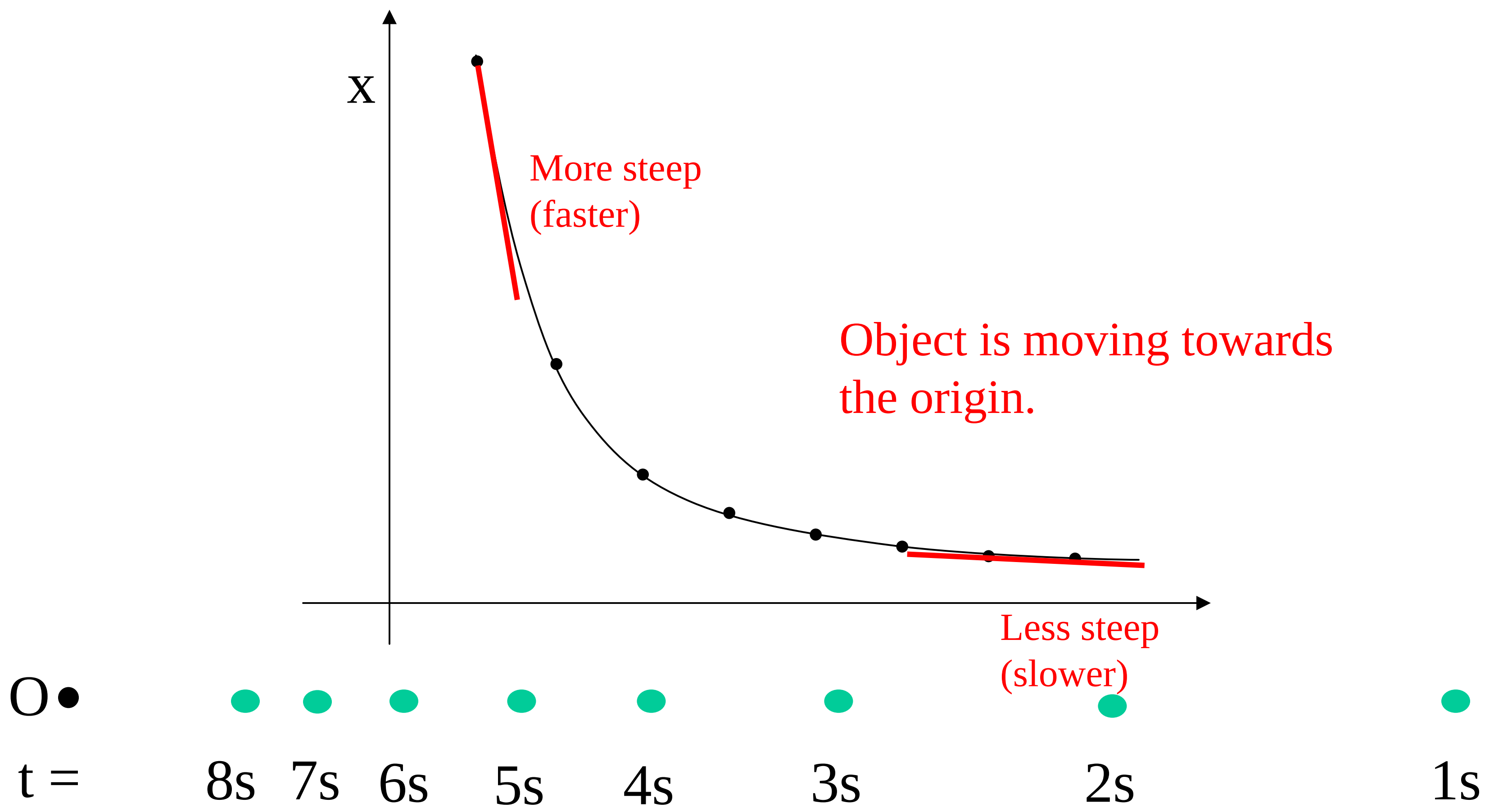



Object is traveling towards the right, with a decreasing speed (i.e. slowing down)

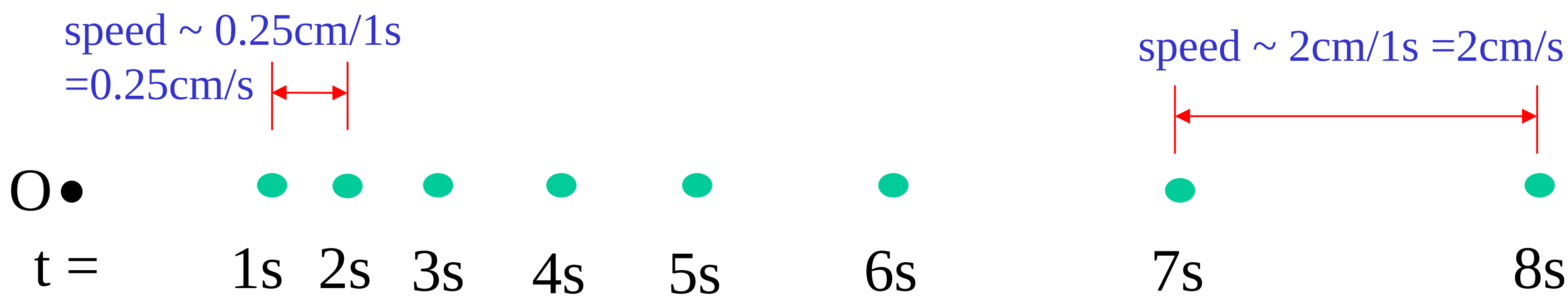
# Graph for Non-uniform Motion - slowing down



Here's a graph for an object which is slowing down, but is moving toward decreasing values of x (e.g. toward the left).

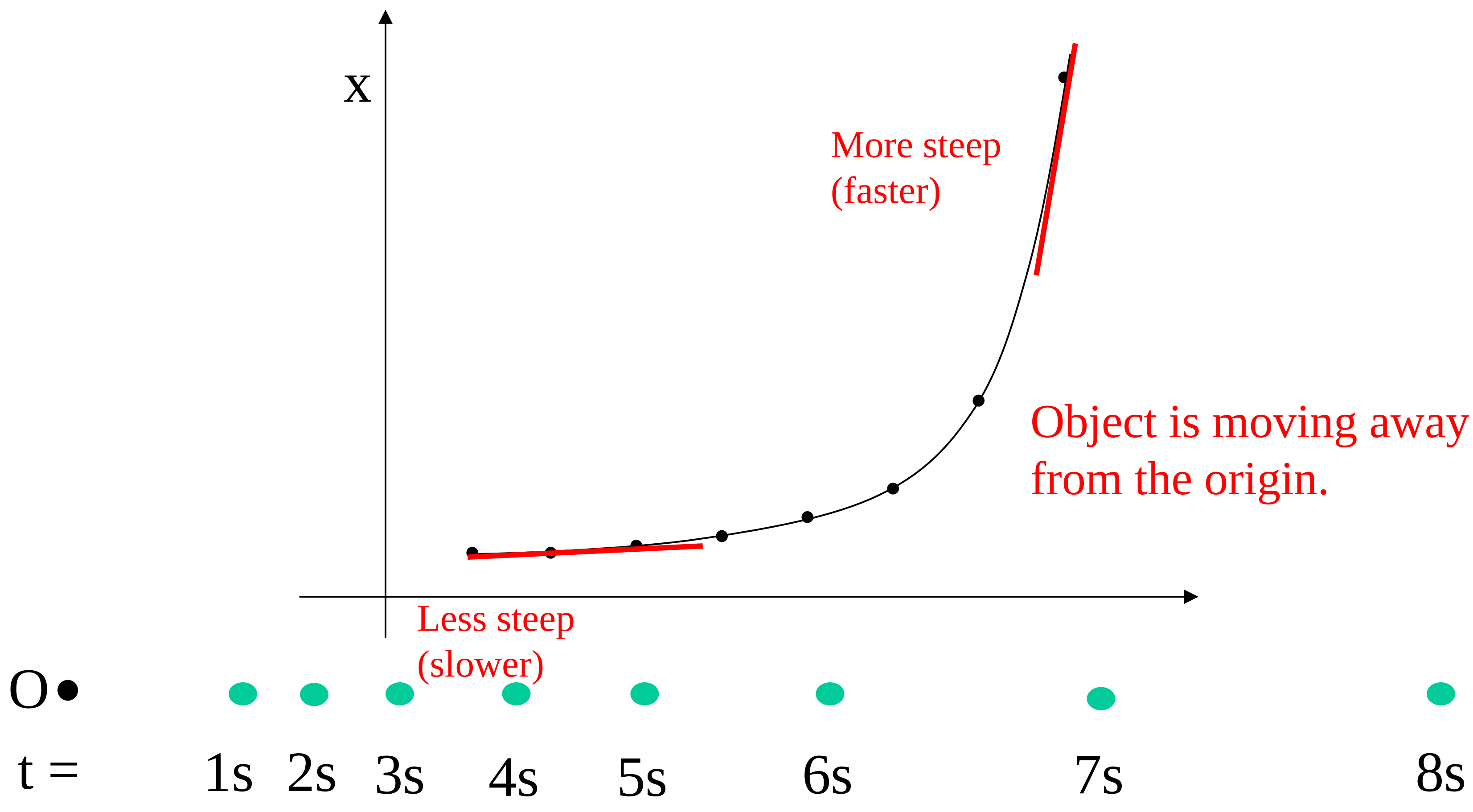


# Non-uniform Motion -speeding up

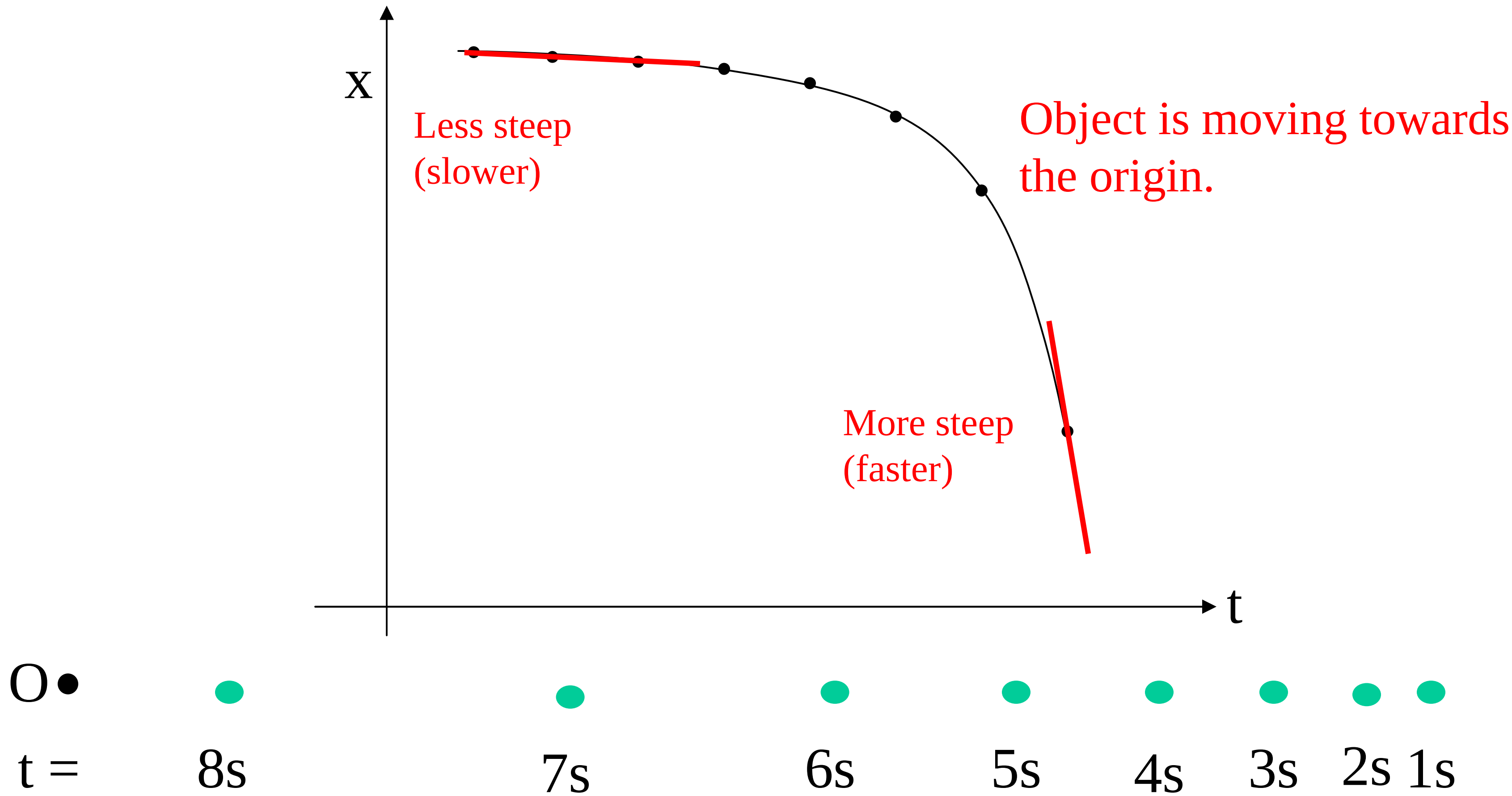



Object is traveling towards the right, with an increasing speed (i.e. speeding up)

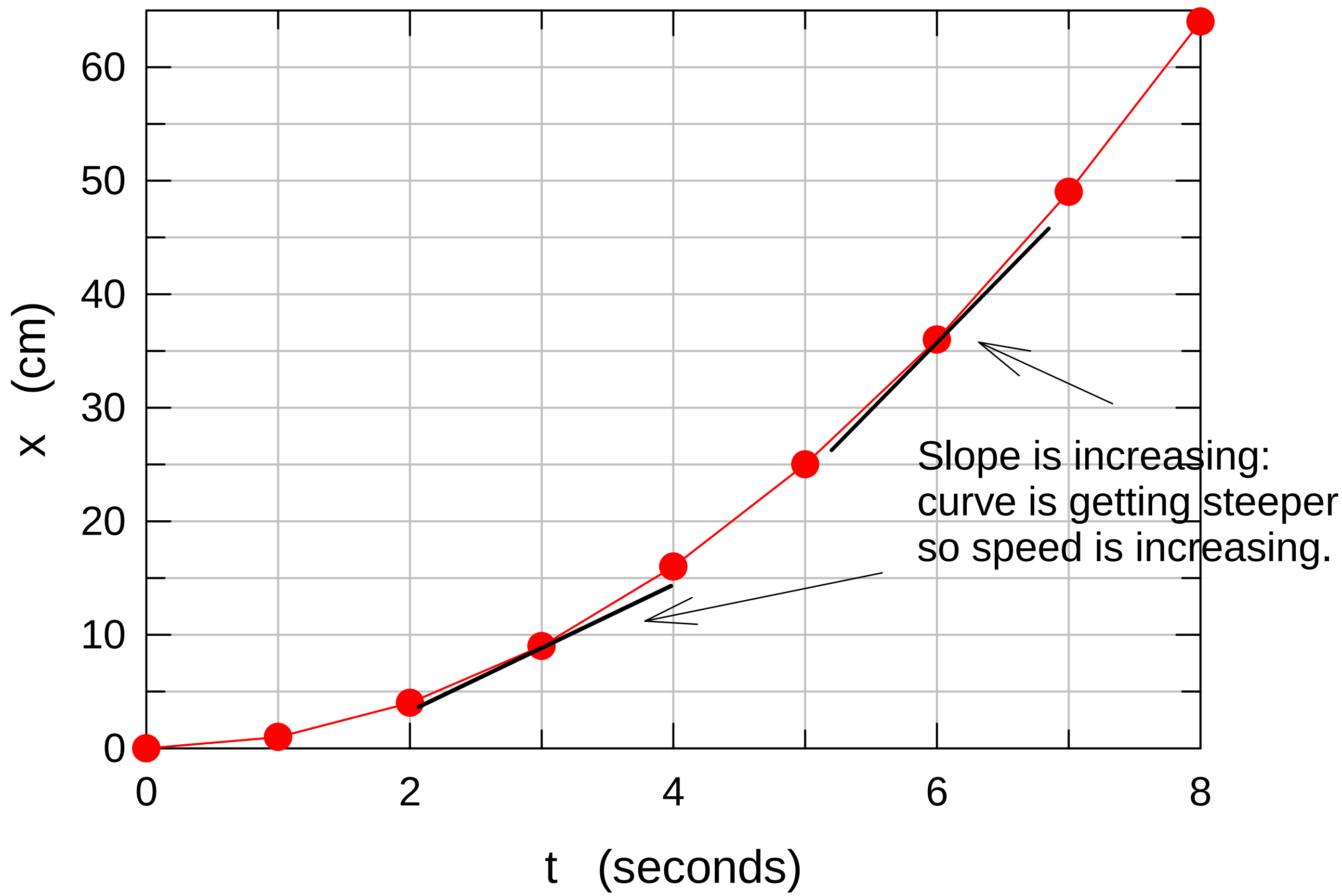
# Non-uniform Motion –speeding up



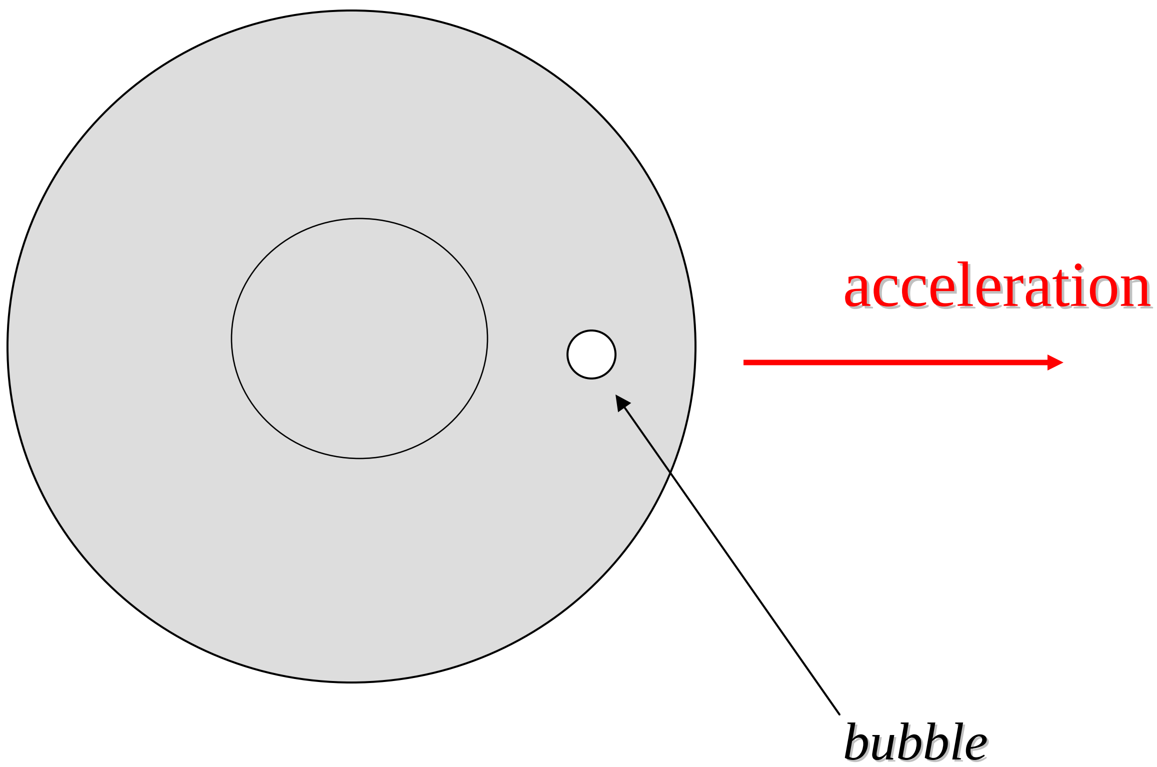
Here's a graph for an object which is speeding up, but is moving toward decreasing values of x (e.g. toward the left).



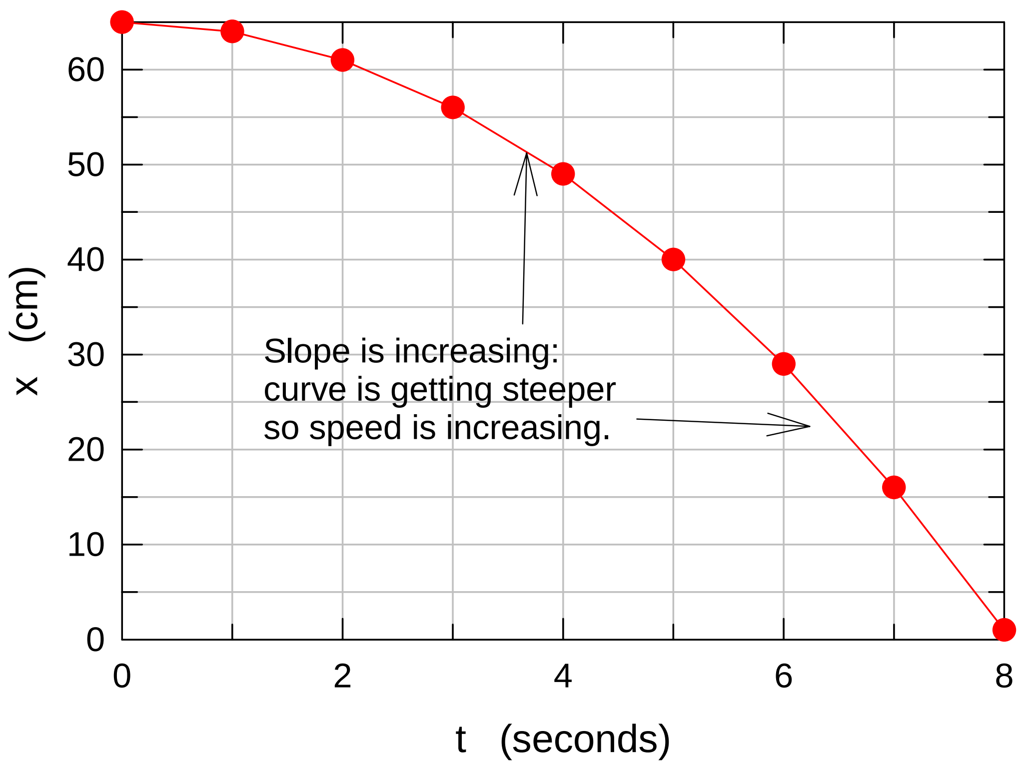
An object which does not have constant velocity is said to be "accelerating" – the ***acceleration*** is the rate of change of the velocity. For straight line motion, acceleration shows up as a curved graph of position vs. time. The greater the acceleration, the more curved.

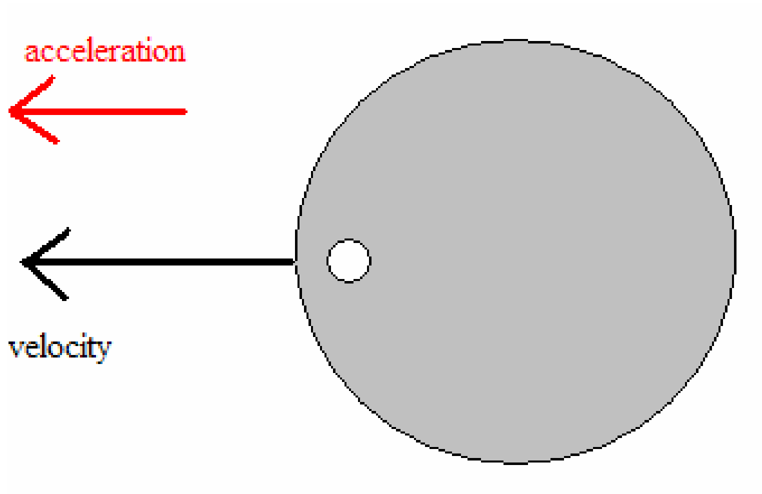


*The bubble in a level will be displaced in the direction of acceleration, no matter which way the level is moving: its position does not depend on the velocity of the level, just the acceleration!*

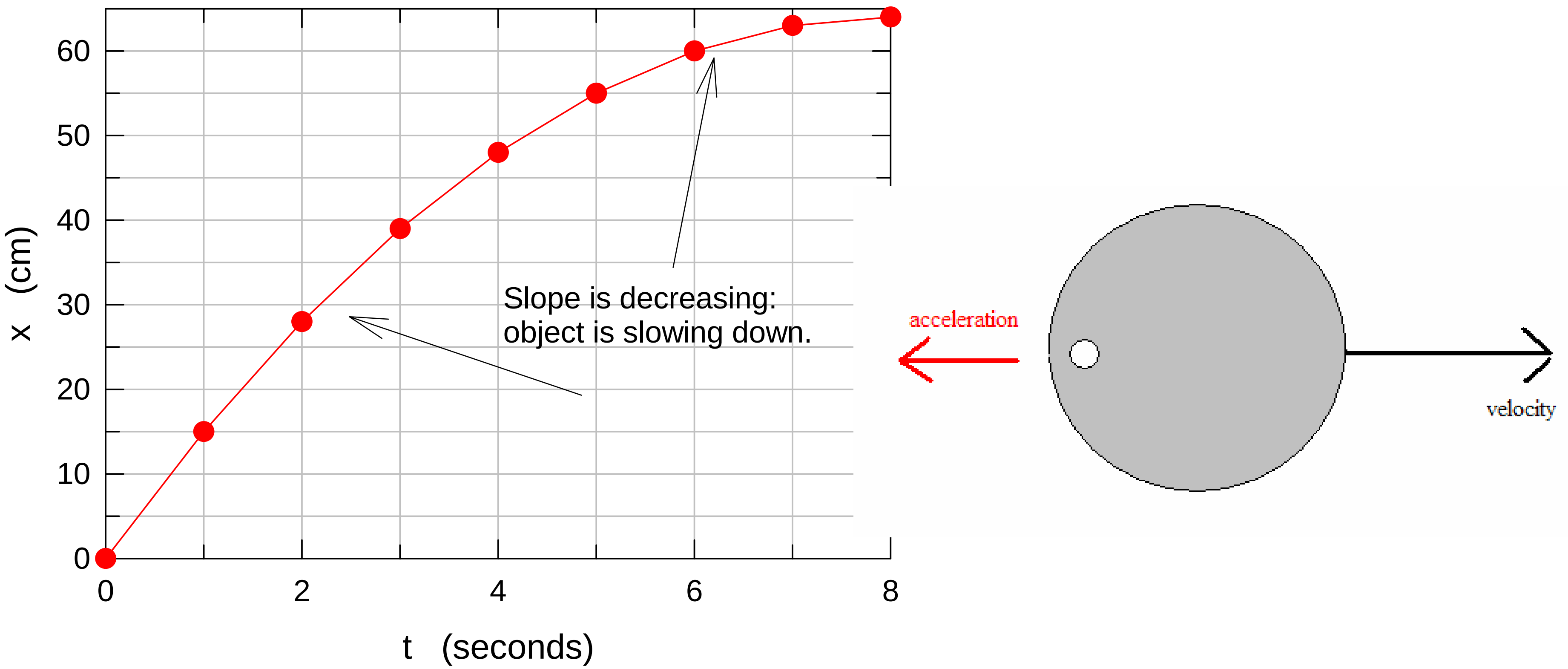


Here's a graph for a particle moving toward decreasing x but speeding up: its velocity and acceleration both point in the "negative" direction (e.g. to the left).



Here's a graph for an object moving in the positive direction but slowing down: it's velocity and acceleration are in opposite directions.



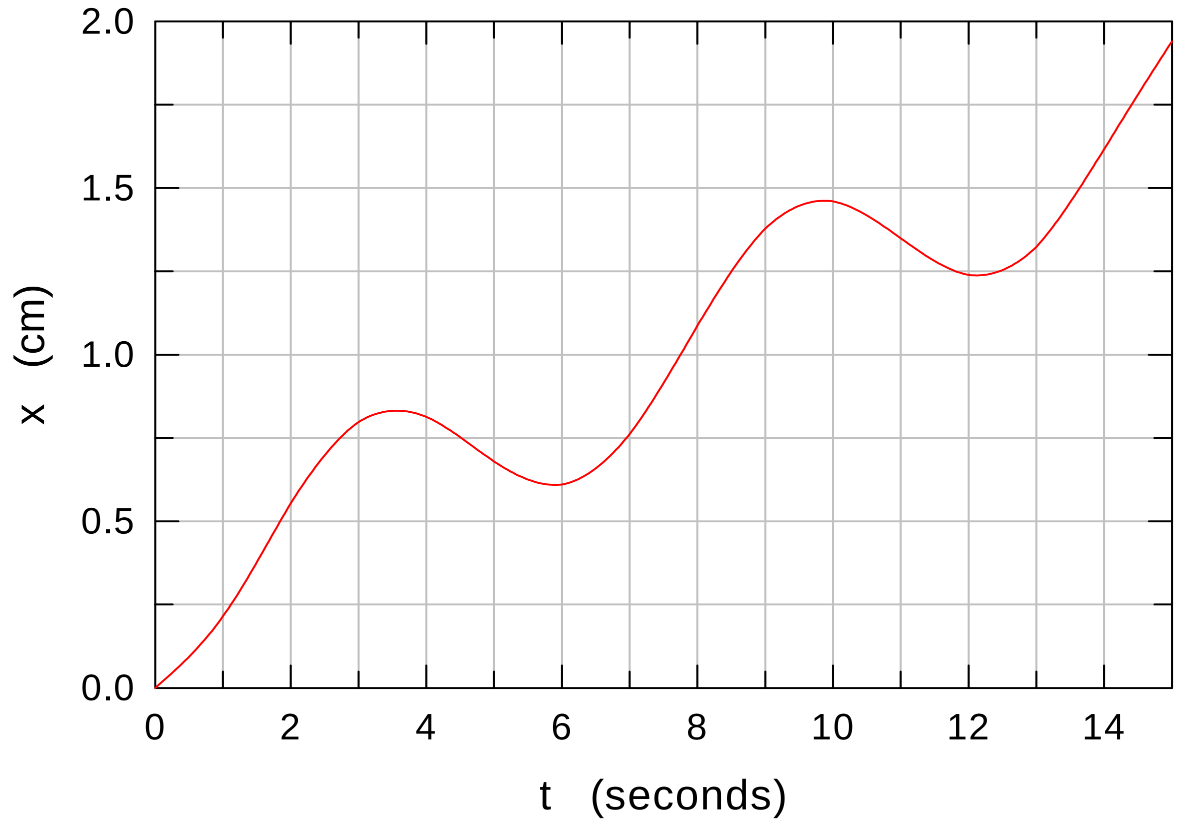
Consider the motion graphed here and answer the following questions:

a) When is the speed = 0?

b) When are the velocity and acceleration in the same direction (i.e. object is increasing speed)?

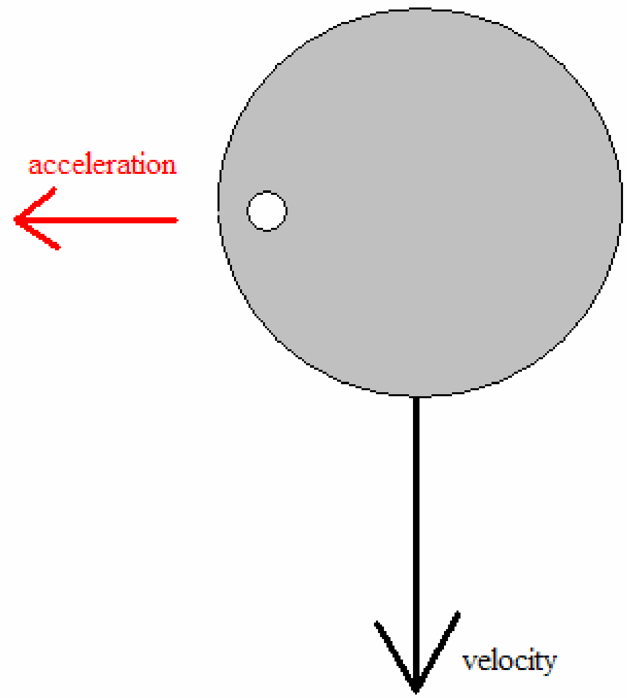
c) When are the velocity and acceleration in opposite directions (i.e. object is decreasing speed)?

d) Are there times when the velocity is (approximately) constant (so the acceleration is ~ 0.)?



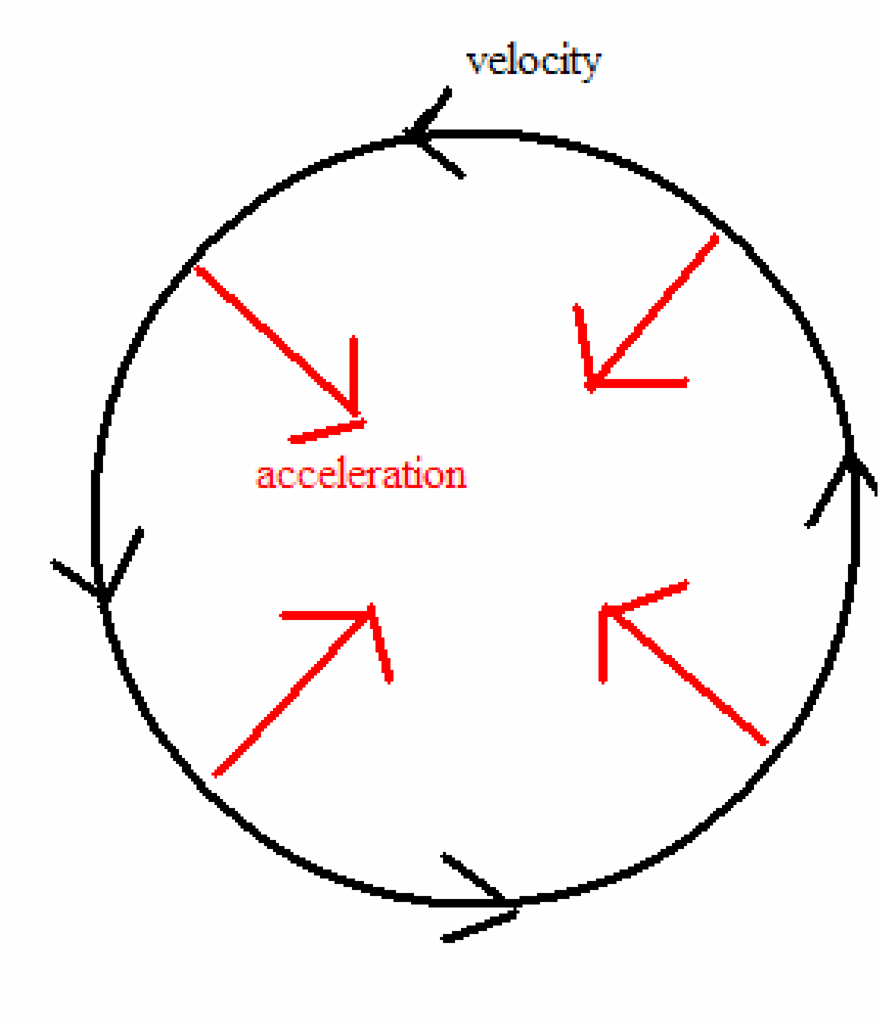
The velocity and acceleration can even be perpendicular to each other, in which case the object turns!

*Which way would this object turn?*



If an object continues turning, it will travel in a circle! Note that the acceleration points in toward the center of the circle so is perpendicular to the velocity.

Note that, since the direction of motion keeps changing, the velocity is not constant (so the object is always accelerating), even if the speed is constant.



# Newton's First Law of Motion

Sir Issac Newton
Jan 4, 1643 (Lincolnshire, England)
- Mar 31, 1727 (London, England)

Uniform motion (i.e. constant speed AND moving in one direction)

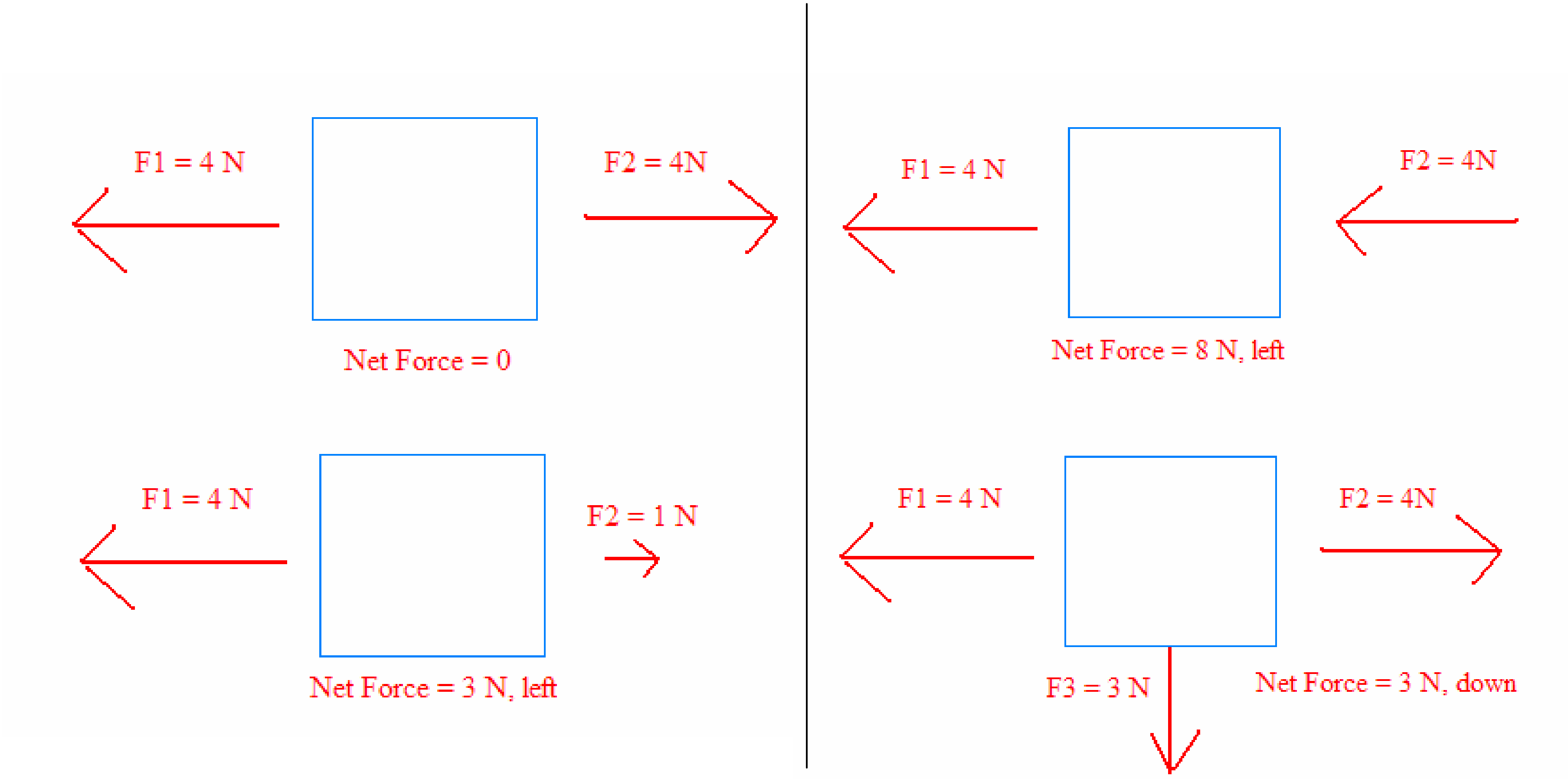
$\updownarrow$

Net (total) force acting on the object = 0

(i.e. all the forces on the object are balanced)

# Combining Forces

*(Forces acting on the same object can be added/subtracted to find the net force on that object.)*




*Metric unit of force is the Newton (N).*

# Implications of Newton’s First Law

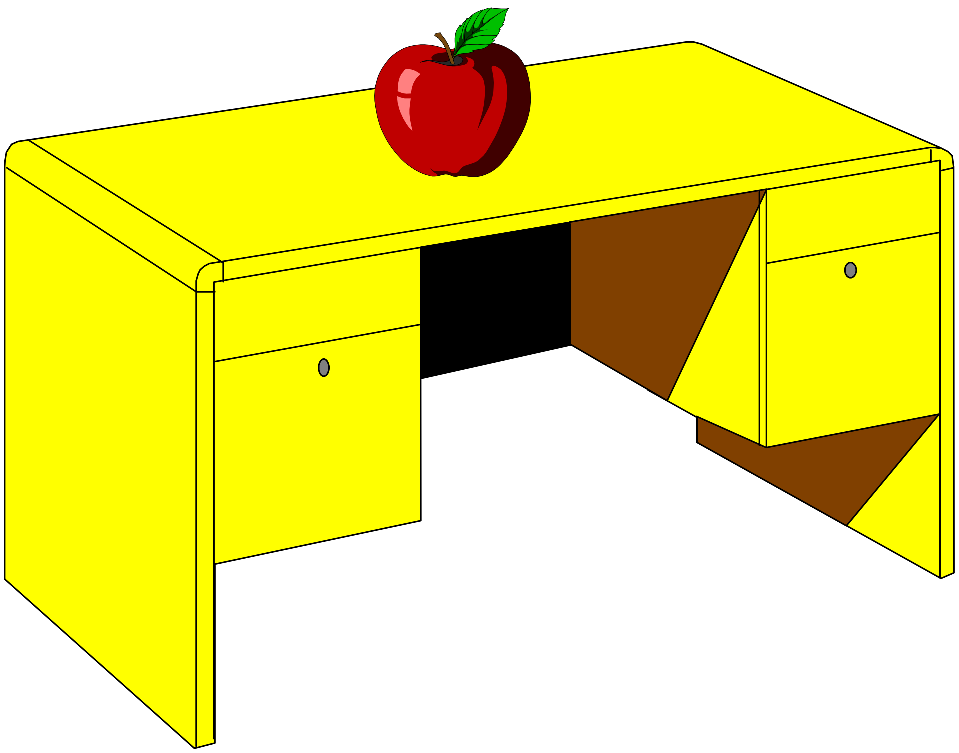
- If you see an object at rest, or moving in a straight line with uniform speed, the total force must be balanced and add up to zero.
- If all forces are balanced and add up to zero, the object must be moving with a constant velocity.

# Observation I

A spaceship is moving with uniform motion in outer space. Does it need any fuel?

How about if it is speeding up, slowing down, or changing direction of travel?

# Observation II



Is there any force acting on an apple resting on the table top? Are the forces balanced?

What will be the answer if I am pushing the apple to the side so that it is moving uniformly on the table top?

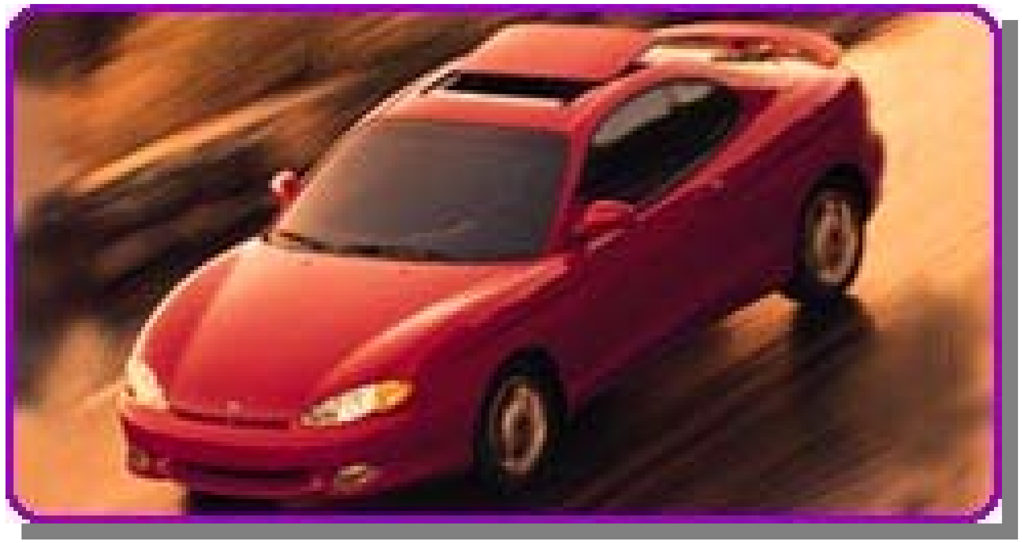
# Observation III

What are the forces acting on you when you are free falling? Are the forces balanced?

What will happen if you open your parachute, or after you reach the terminal speed?

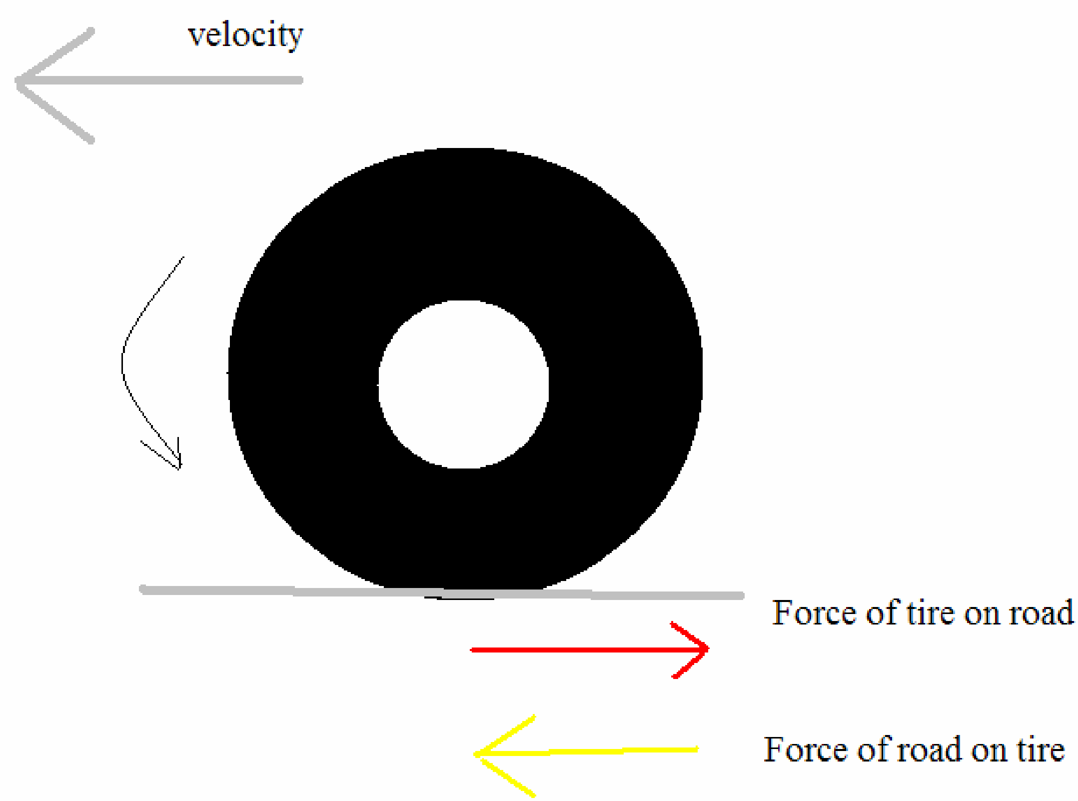
# Observation IV

You are driving a car on a straight highway at a constant speed of 65 mph. What is the total force acting on the car?



If you are driving at constant velocity (speed and direction), the net force on the car must be zero.

# Where does the force of the road on the tires come from?



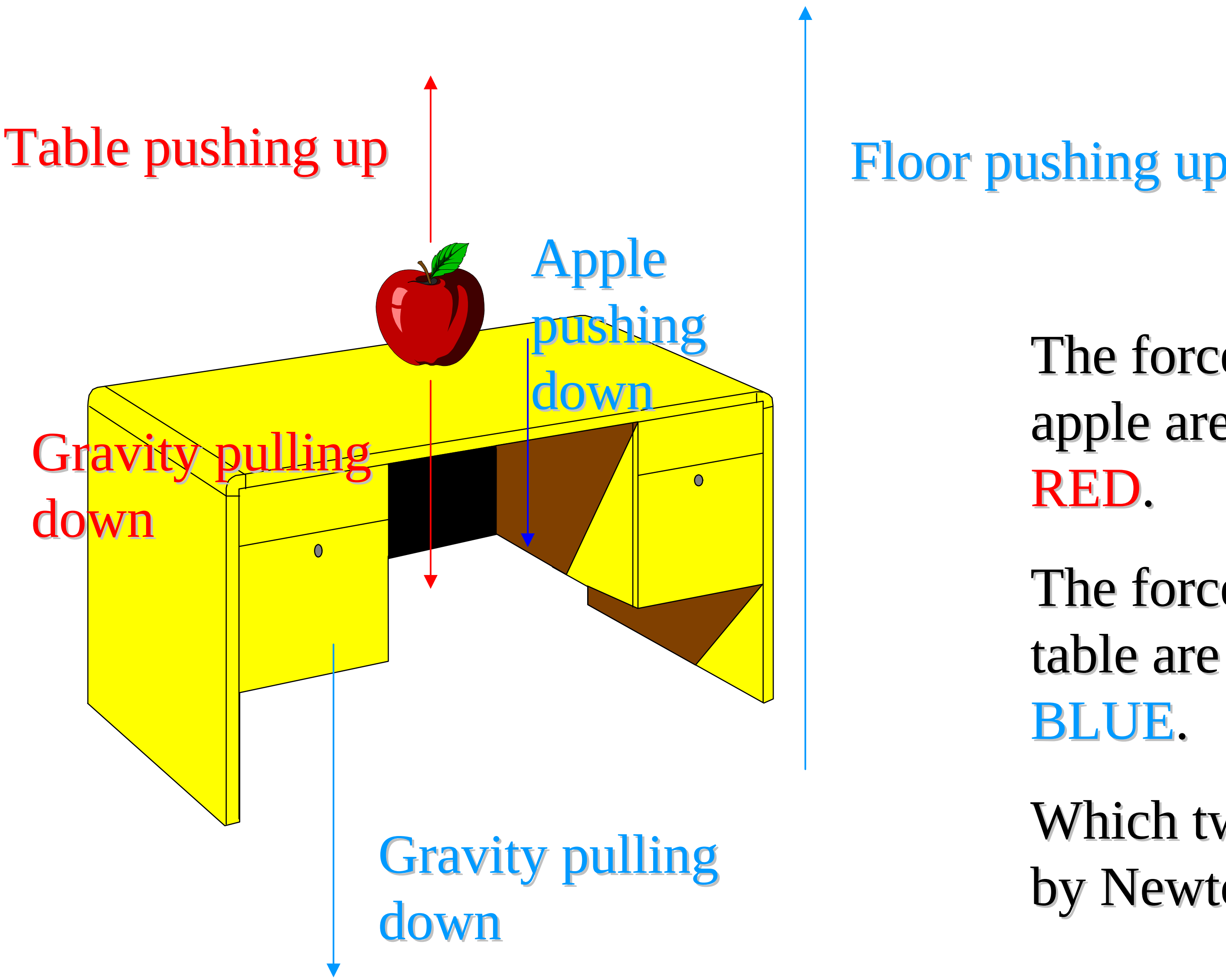

*When the engine turns the wheels, the tires push backwards on the road. The road, in turn, pushes forward on the tires.*

*This is an example of* **Newton's Third Law**.

# Newton's Third Law

***For any two objects A and B, the force of A on B is equal and opposite to the force of B on A.***

(Note that this law relates forces on different objects – don't combine them to find a net force!!)



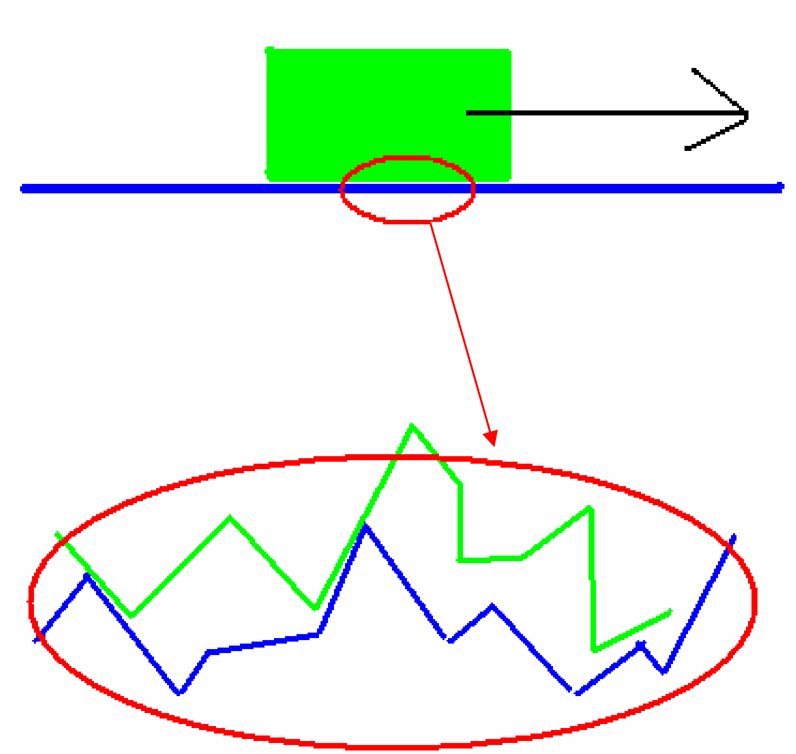

The forces on the apple are shown in RED.

The forces on the table are shown in BLUE.

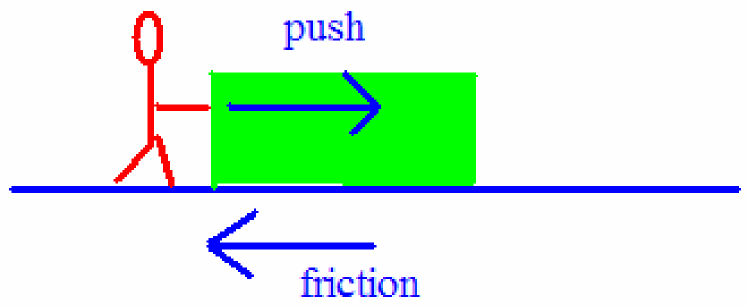
Which two are related by Newton's 3rd Law?

# Friction

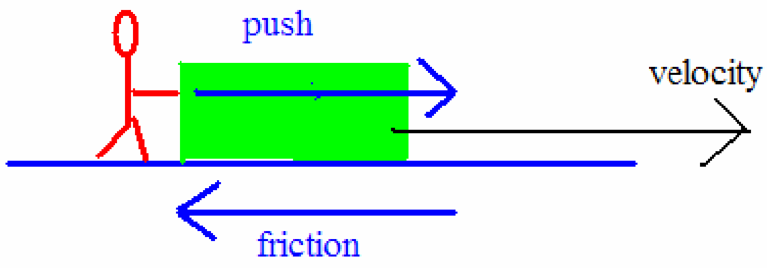
**Friction** is a force encountered when objects ***slide*** (not roll) across each other. It is caused by the fact that no surface is perfectly smooth, and the jagged bumps can get caught on each other. The rougher the surfaces, the greater the friction.



- *In the top picture, the boy is pushing on the box, but the force of friction exactly opposes his push, so the box doesn't move.*




- *In the bottom picture, he pushes harder and can get the box to slide.  If the box slides at constant velocity, however, the frictional force again exactly balances his force.*



# Newton's Second Law

***What it the net force on an object is NOT zero?***

It's velocity changes – i.e. it accelerates (**Newton's 2nd Law**):

**The net force on an object equals its mass times its acceleration, F = ma**.

The acceleration is in the same direction as the net force:

- If the net force is opposite its velocity, it slows down.
- If the net force is in the direction of the velocity, it speeds up.
- If the net force is perpendicular to the velocity, it turns.

# F = ma


Force of pavement on bike

acceleration

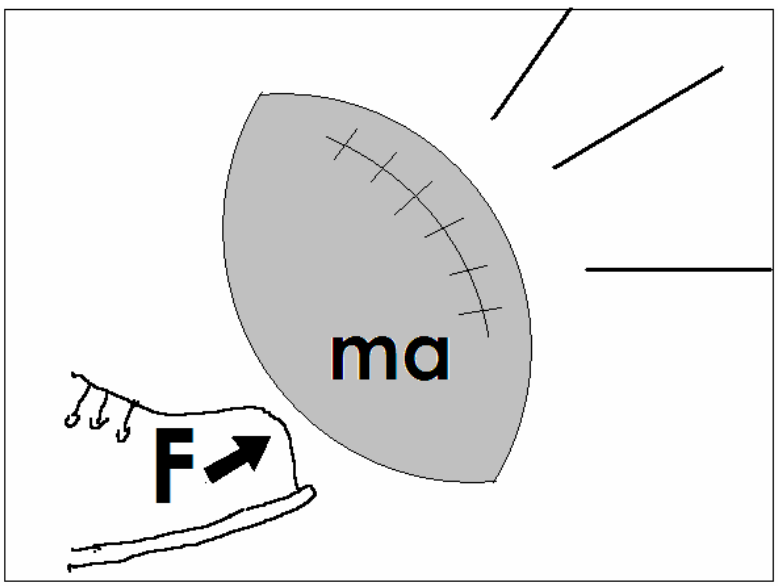
Note that the amount of acceleration is inversely proportional to the mass, the "***amount of stuff***":

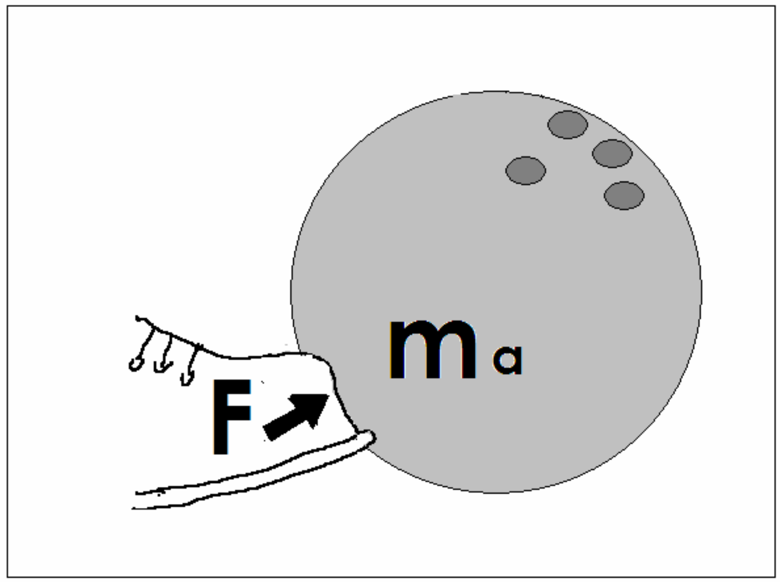
$$a = F / m$$

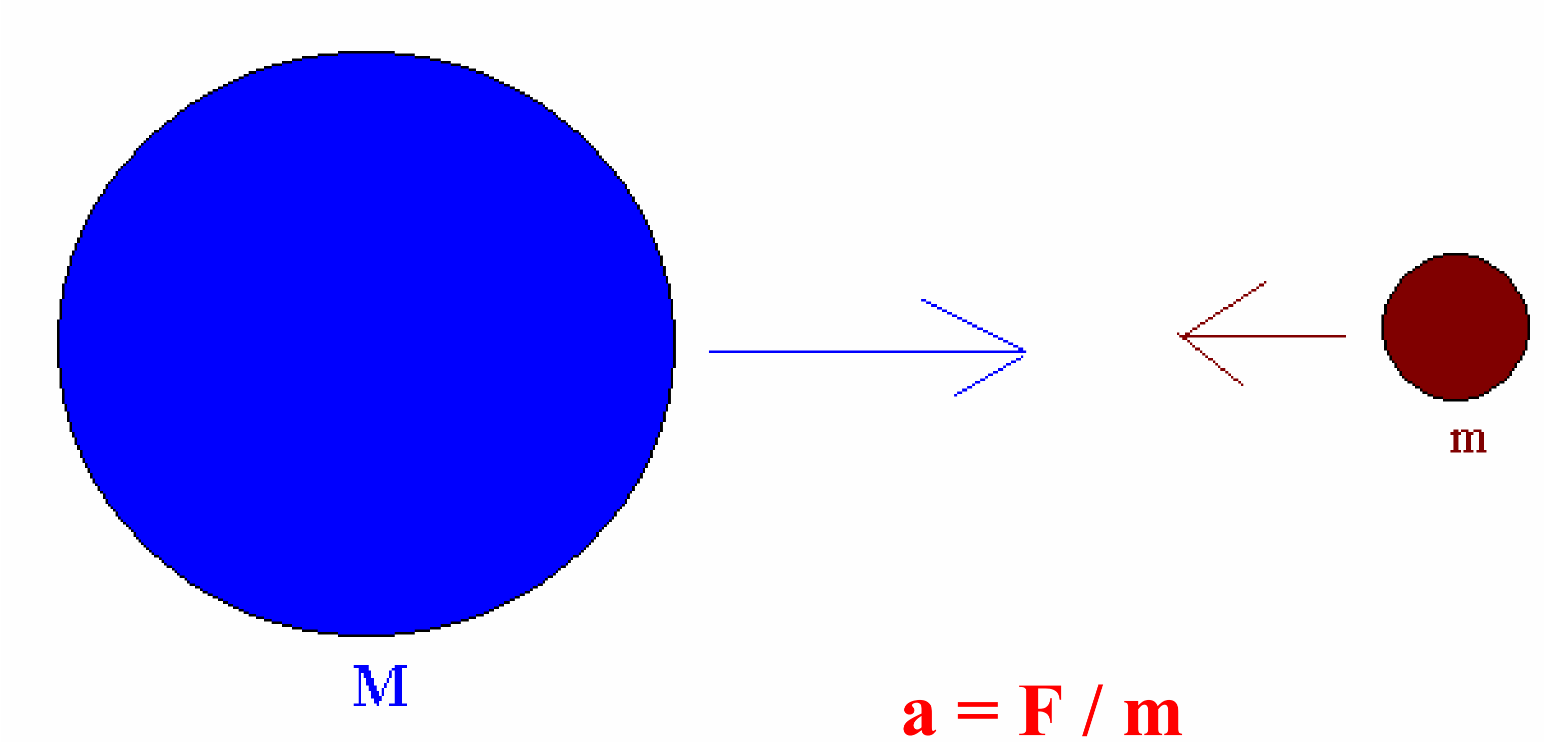
Mass is measured in grams or kilograms.

## $a = F / m$

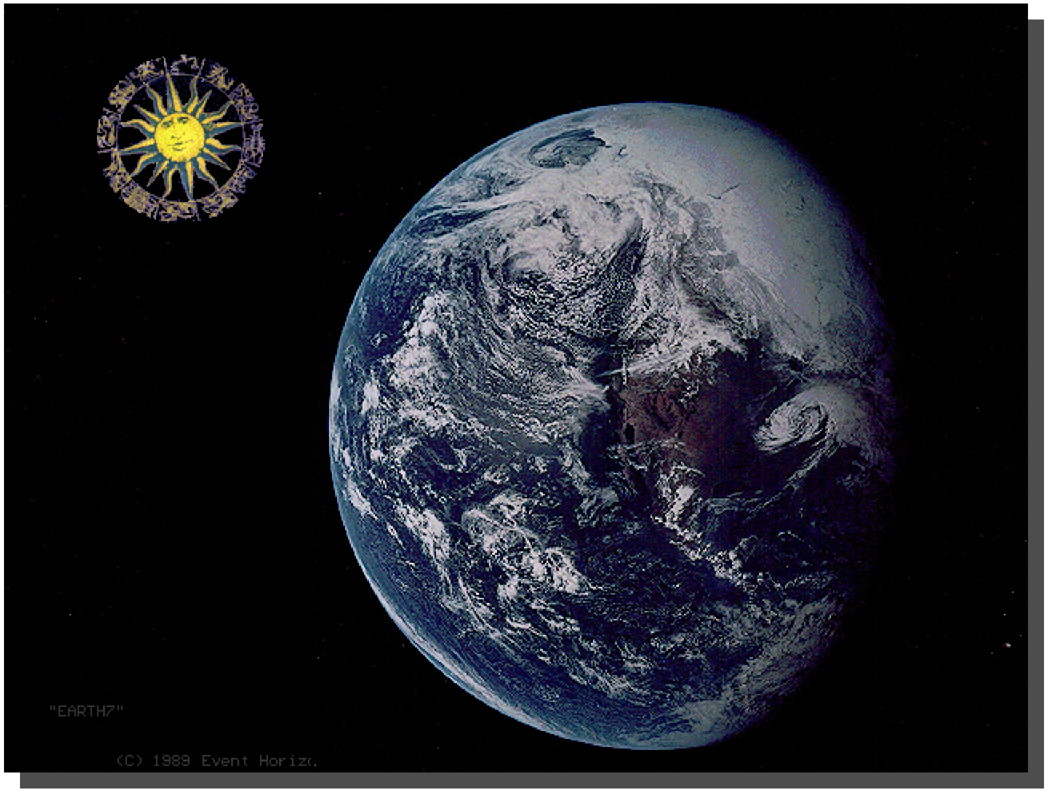
*If you kick the balls with the same force, which will accelerate more?*





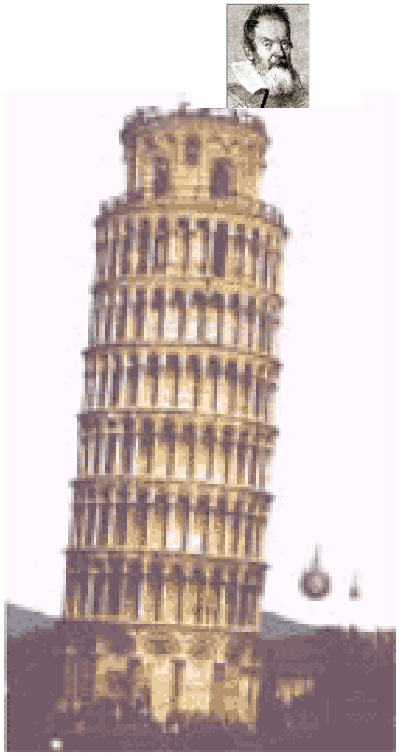

*When the two masses collide, their forces on each other will be "equal and opposite" (Newton's 3rd Law) – which one will accelerate more as a result?*



Earth is revolving around Sun with a constant speed. Is the earth accelerating? If so, in what direction?

Is there any force acting on Earth?

What is the force and its direction (if any)?



**Objects of Different Mass Fall at the Same Rate**

A cannon ball and a musket ball, dropped from the Leaning Tower of Pisa, would hit the ground at the same time.

# Gravity

The force of gravity on an object is called its **weight (W).**

Gravity is a very peculiar force: every object falling only under the influence of gravity ("free fall") falls with the same acceleration (Galileo's discovery)!

But $\mathbf{a = F(gravity)/m = W/m}$. Since every object in free fall has the same acceleration, this implies that the weight (i.e. the gravitational force) is proportional to mass (the measure of inertia).

*Because everything free falls with the same acceleration, the girl and apple will fall together (until the parachute opens).*

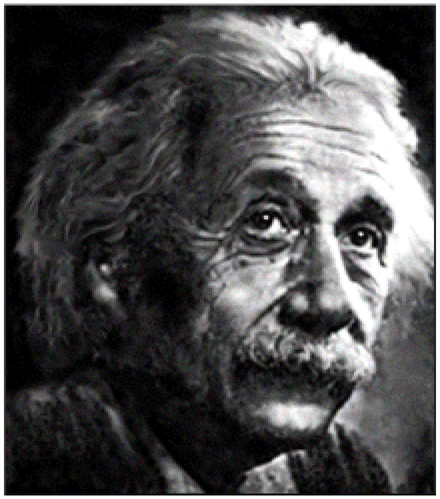
*Near the surface of the earth, the ratio of W/m for every object is*

**W / mass ~ 9.8 N/kg**

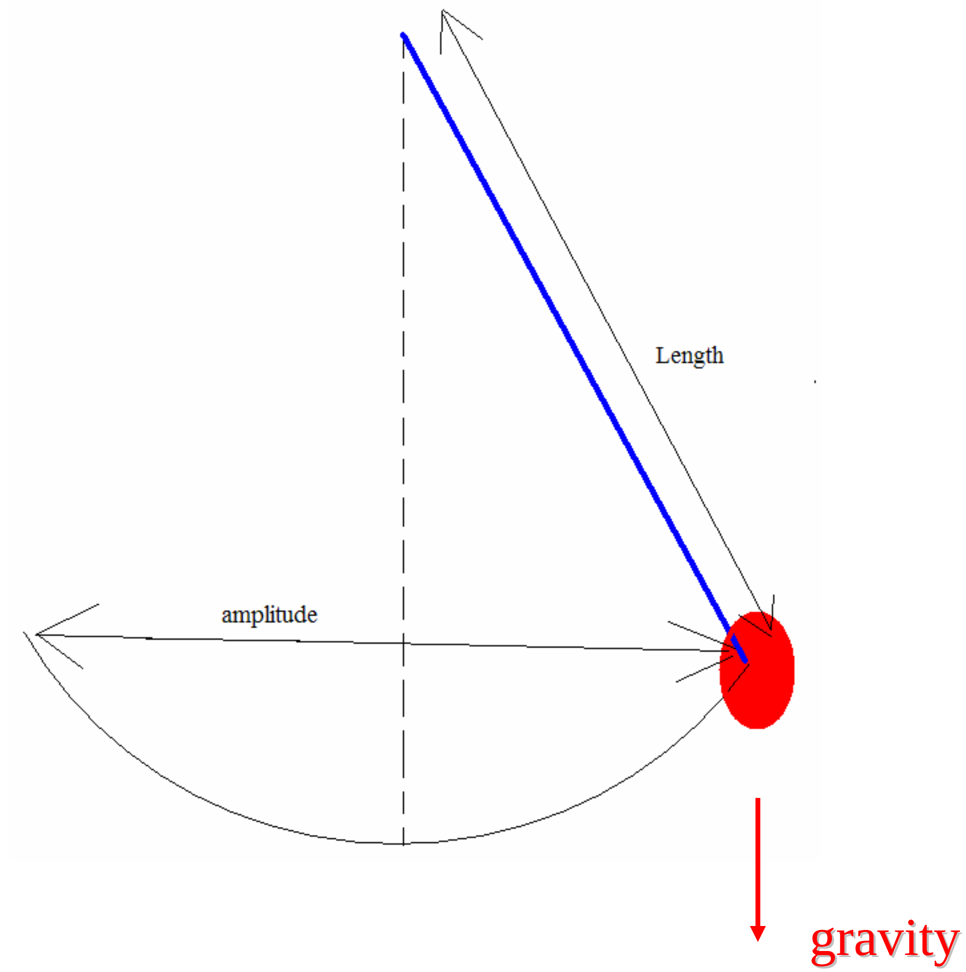
-- *i.e. a 1 kg object will weigh 9.8 N. (The ratio does vary with location – it's a lot more on Jupiter and a lot less on the moon.)*

That the inertial mass (the mass in Newton's 2nd Law) is the same as the mass that appears in the Law of Gravity (the "Equivalence Principle")– seemed like such a coincidence, that physicists have done lots of experiments to see if there may be a small difference – i.e. if different object fall at different rates.  So far, no difference has been found.

Einstein, hating coincidences, made the equivalence principle the basic assumption of his **Theory of General Relativity** – that all things fall at the same rate because **space itself is warped by gravity!**



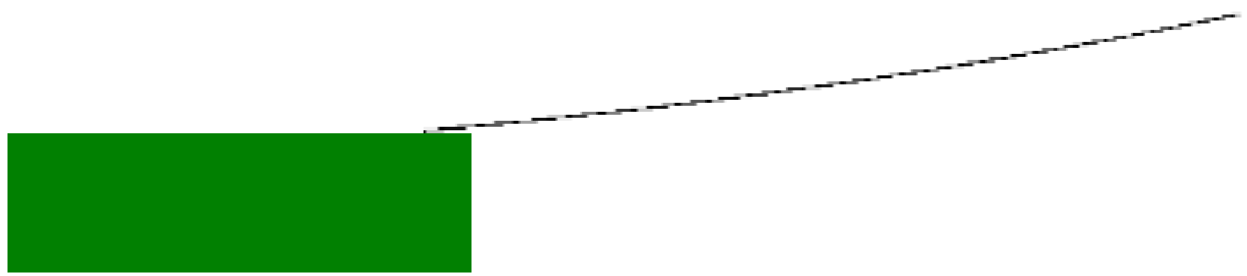
# The Pendulum




*Galileo realized that since the acceleration of gravity is the same for all objects, the period of a pendulum (time for one oscillation) is independent of its mass. It is also independent of its amplitude.*

*The period only depends on its length:* the longer the pendulum, the longer its period.

# Vibration



Longer ruler $\Rightarrow$ lower pitch (longer period)

Shorter ruler $\Rightarrow$ higher pitch (shorter period)

The longer the ruler, the longer the period (*like the pendulum*).

# Vibration

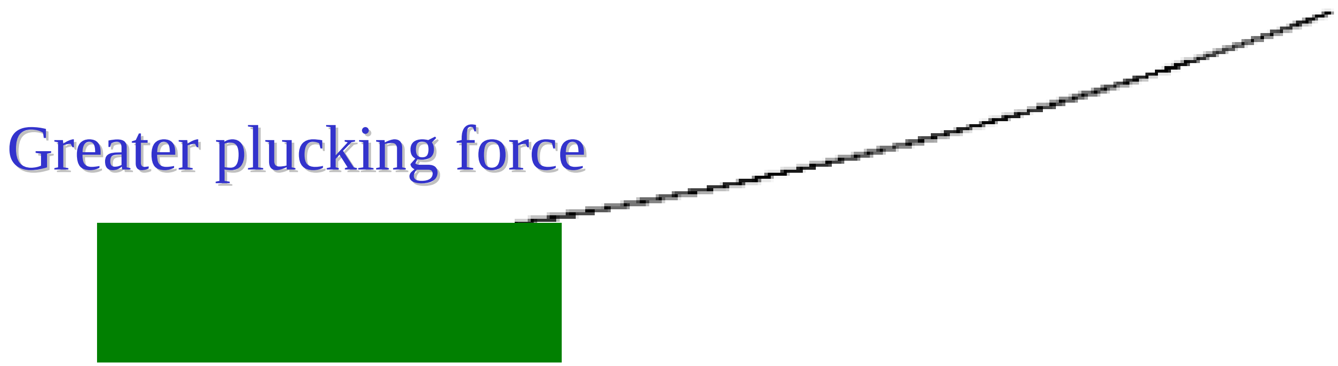
Smaller plucking force

Longer ruler $\Rightarrow$ lower pitch

Shorter ruler $\Rightarrow$ higher pitch

Large plucking force can produce larger amplitude in vibration, but has no effect on the pitch (*just like the pendulum*).

# Vibration

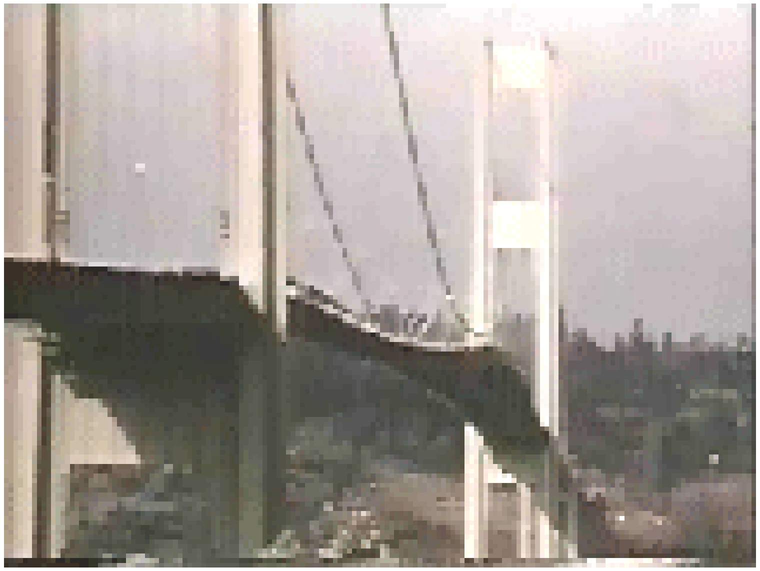



Longer ruler $\Rightarrow$ lower pitch

Shorter ruler $\Rightarrow$ higher pitch

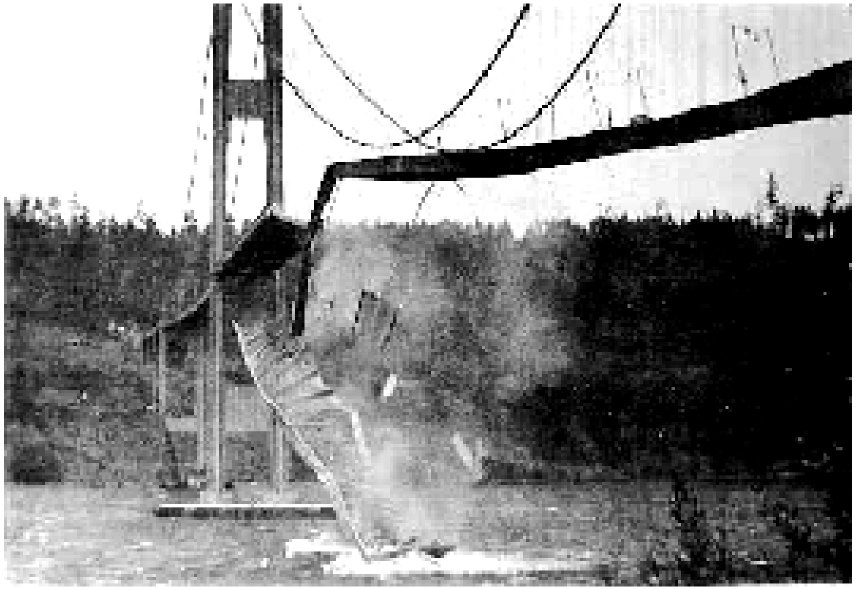
Large plucking force can produce larger amplitude in vibration, but has no effect on the pitch.

# Everything has its own natural pitch



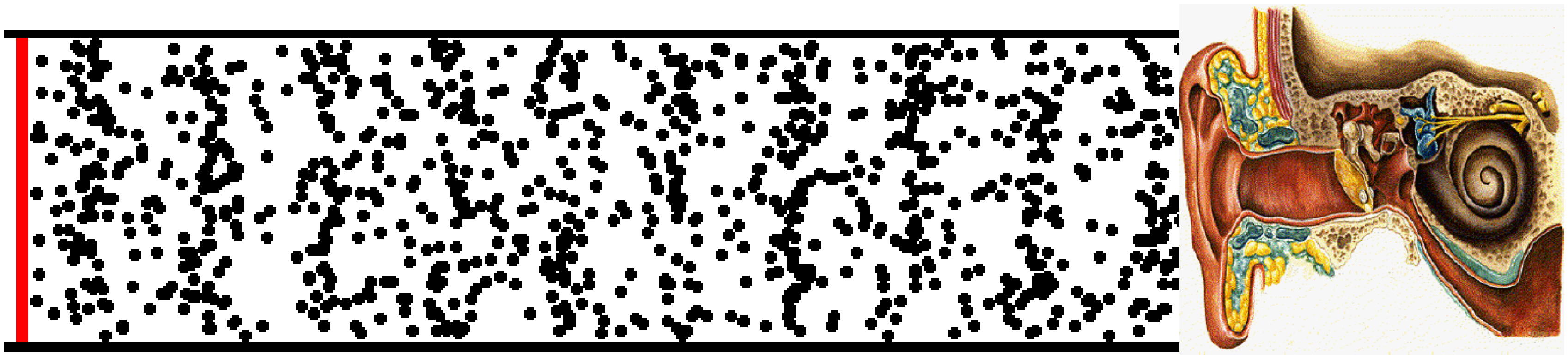
This bridge is vibrating once every 5 seconds!

# The Fate of Bridge Tacoma



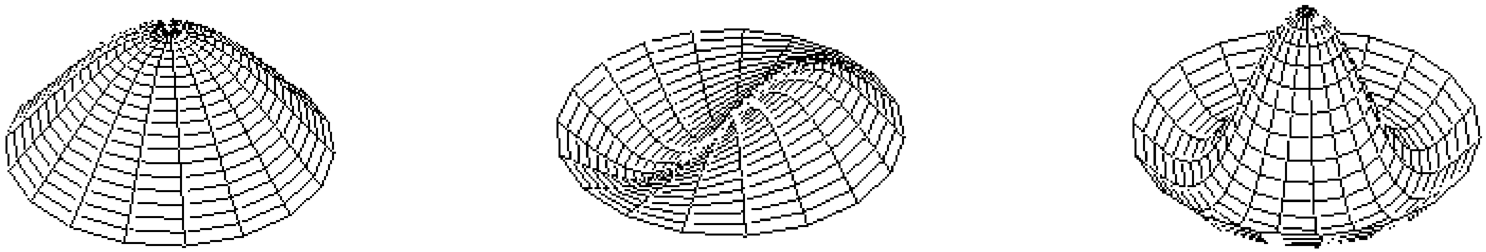
November 7, 1940   ~11:00 a.m.

# Vibration produces sound

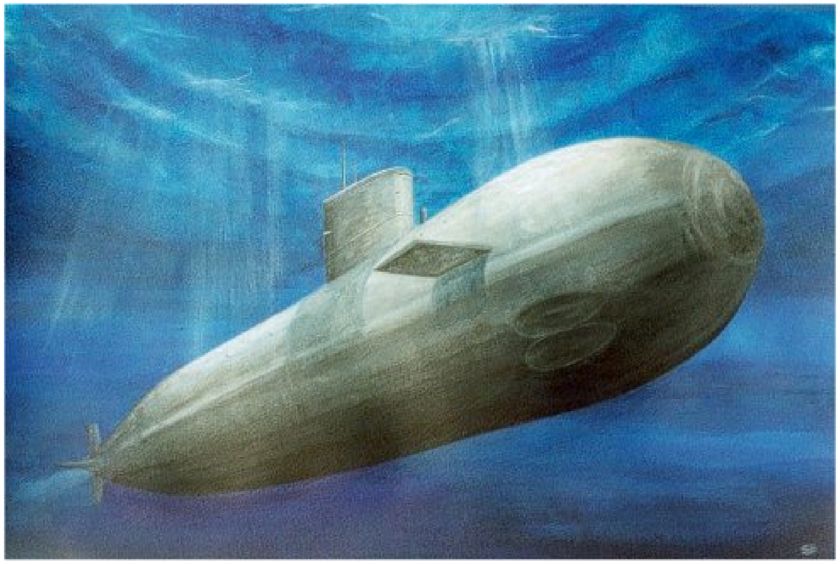


Sound propagates through air

# Sound produces vibration



# Sound propagates better in water



# Sound travels best through solid