L-3 Gravity and Free Fall

- Review – Principle of inertia (Galileo)
- Inertia: the tendency of objects to resist *changes in motion*.
  - If an object is at rest, is stays at rest.
  - If an object is moving with constant velocity, it continues moving with constant velocity unless something stops it.
- The inertia of an object is measured by its mass in kilograms (kg) – the quantity of matter in it.

Forces can change velocity

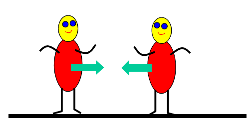
- No force is required to keep an object moving with constant velocity.
- acceleration is a change in velocity
- A net force must be applied to an object to produce an acceleration
- For example:
  - If an object is at rest, you must push it to get it to move
  - If it is moving, a force must be applied to stop it, e.g., friction, air resistance

The force of gravity

- We will first consider a common force that can accelerate an object: gravity
- As an object falls its velocity constantly increases; the velocity of an object thrown upward constantly decreases as it rises
- The force of gravity depends on the mass of the object
- Gravity keeps us on Earth, the Moon in its orbit, and the Earth in orbit around the Sun; gravity holds the Universe together.

Weight and gravity

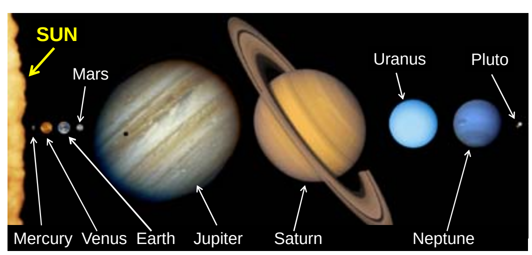
- All objects exert an attractive force on each other – ***Newton's Universal Law of Gravity***
- Your ***weight*** is the attractive force that the earth exerts on you → it is what makes things fall!
- All objects are pulled toward the *center of the earth* by gravity.
- The Sun's gravity holds the solar system together.
- It is a non-contact force→ no touching required!



Newton's Law of Gravity

- the force of gravity depends on how large the masses are ➔ big M's ➔ big force,
- and, how far apart they are, the closer the masses ➔ the bigger the force
- *Since we are closer to the Earth than to the Sun, our gravitational force is mainly due to the Earth*

THE SOLAR SYSTEM



The Sun is the most massive object in the solar system, about 3 million times the Earth's mass, and 1000 times more massive than the most massive planet - Jupiter.

A little astronomy

- The planets revolve around the sun in *approximately* circular paths (Kepler)
- The further the planet is from the sun the longer it takes to go around (Kepler)
  - the time for a planet to go completely around the sun is a year
  - the earth spins on its axis once every day
  - the moon revolves around the earth about once every month

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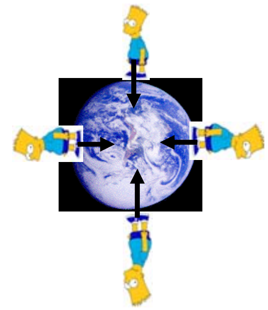
What does your weight depend on?

- The weight w of an object depends on its mass and the local strength of gravity- we call this ***g***
- ***g** is the acceleration due to gravity*
- Wherever you are on the earth, it pulls you with a force that points to the center of the earth



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What is this thing called g?

- g is something you often hear about, for example you might hear that a fighter pilot experiences 2 g's when turning his jet.
- g is the acceleration due to gravity
- When an object falls its speed *increases* as it descends; the speed of a rising object *decreases* as it ascends
- g is the amount by which the speed of a falling object increases each second – about 10 meters per second each second or 10 m/s^2
- A more precise value for g is 9.80665 m/s^2, but we will use **g ≈ 10 m/s^2** in this course

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Example – a falling object

time	velocity
0 s	0 m/s
1 s	10 m/s
2 s	20 m/s
3 s	30 m/s
4 s	40 m/s
5 s	50 m/s

+ 10 m/s
+ 10 m/s
+ 10 m/s
+ 10 m/s
+ 10 m/s

Change in velocity, or acceleration ≈10 m/s/s or, 10 m/s^2

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Snapshots of a falling ball taken at *equal* time intervals

Ball starts falling here from rest

the ball falls through larger distances for each second that it descends

red arrows are velocity
green arrows are displacement

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How to calculate weight

- Weight (w) = mass (m) x acceleration due to gravity (g)
- **w = m × g = mg**
- Units to be used in this formula:
  - m is in kilograms (kg)
  - g ≈ 10 m/s^2
  - w is in force units called Newtons (N)

≈ means approximately equal to

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example

Question: What is the weight of a 100 kg object?

Answer: $w = m \times g = 100 \text{ kg} \times 10 \text{ m/s}^2 = 1000 \text{ N}$

- One Newton is equal to 0.225 pounds (lb), so in these common units 1000 N = 225 lb
- *Often weights are given by the equivalent mass in kilograms. We would say that a 225 lb man "weighs" 100 kg; this is commonly done but, it is technically incorrect.*

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Compared to Earth, you weigh more on Jupiter and less on the Moon

- Your mass is the same everywhere, but your weight depends on where you are, since g depends on the mass of the planet.
- On the moon $g \approx 1.6 \text{ m/s}^2 \approx$ (1/6) g on earth, so your weight on the moon is only (1/6) your weight on earth
- On Jupiter, $g \approx 23 \text{ m/s}^2 \approx 2.3$ g on earth, so on Jupiter you weigh 2.3 times what you weigh on earth

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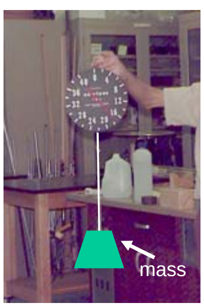
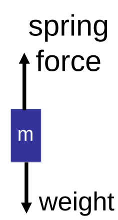
Get on the scale: How to weigh yourself





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Free Fall

- Galileo showed that all objects (*regardless of mass)* fall to earth with the same acceleration → g = 10 m/s²
- This is only true if we remove the effects of air resistance. [feather and quarter]
- We can show this by dropping two objects inside a tube that has the air removed,
- The moon has no atmosphere, because its gravity is too weak to hold onto one [video]

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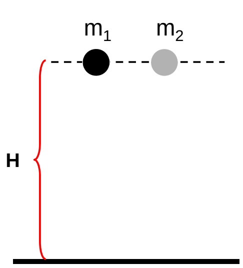
Galileo's experiments



m_1 does not equal m_2

- Galileo showed this by dropping 2 objects of different mass, from the same height, H, and measuring how long they took to reach the ground
- If H isn't too big, then air resistance is not a big effect

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On the other hand . . .

- If you drop an object from a small height it falls so quickly that it is difficult to make an accurate measurement of the time
- We can show experimentally that it takes less than half a second for a mass to fall 1 meter. (demo)
- Galileo did not have an accurate clock, so he reduced the effect of gravity by using inclined planes

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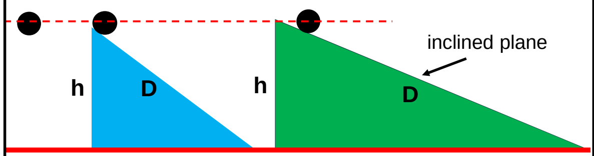
Galileo used inclined planes to reduce the effect of gravity



$$g_{\text{straight down}} = 10\ m/s^2$$

$$g_{\text{down inclined plane}} = g_{\text{straight down}} \times \frac{h}{D}$$

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What did Galileo learn from the inclined plane experiments?

- He measured the time it took for different masses to fall down the inclined plane.
- He found that different masses take the same time to fall down the inclined plane.
- Since they all fall the same distance, he concluded that their accelerations must also be the same.
- By using different distances he was able to discover the relation between time and distance.
- To reduce the effects of friction, Galileo made the balls roll down the inclined plane

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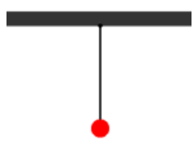
How did Galileo measure time?

Galileo used his own pulse, or a pendulum to measure time.



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