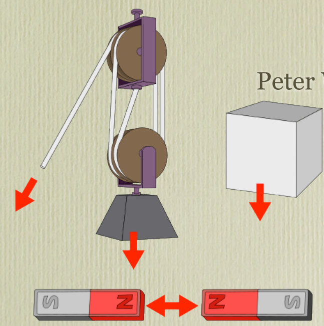
Forces and Motion



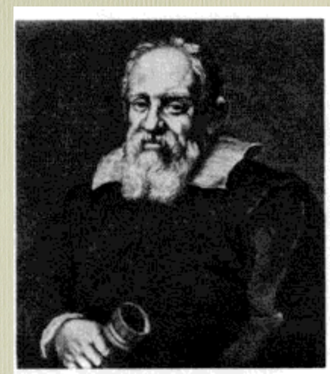
Peter Watson

Wikipedia

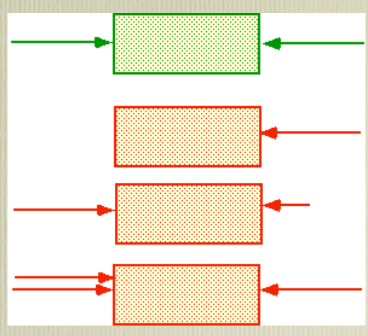
First Law (Galileo's law of Inertia)

- Up to now we have just described motion (kinematics). We now want to explain it (dynamics)

A Body continues at rest or in a state of uniform motion unless acted on by a force.

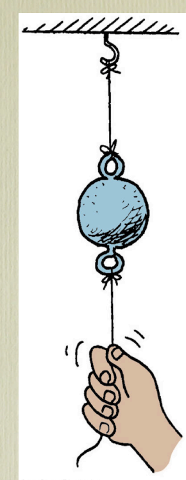


- Uniform motion means no acceleration.
- Note forces can balance: "a force" means "a net force"



At rest?

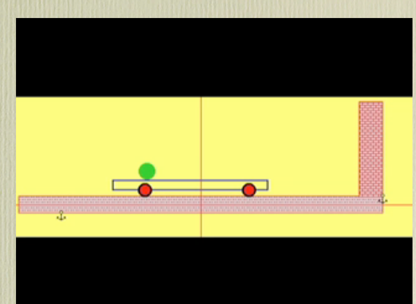
- at rest with respect to what?



Text

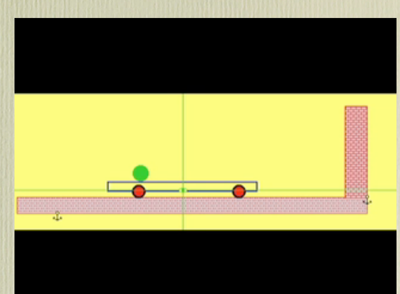
Inertial Frames

- An inertial frame is one that does not accelerate
- Stationary objects stay stationary



Non-inertial Frames

- An non-inertial frame does accelerate
- Stationary objects can accelerate without forces

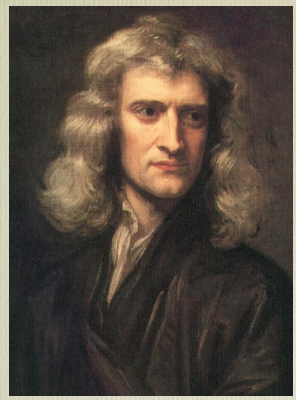


We'll only worry about inertial frames

Newton

- 1642-1727
- Born the day of Galileo's death

William Blake



Second Law

F=ma

- The single most important equation in Physics!

Force = mass x acceleration

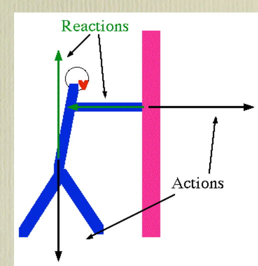
We need to be able to measure forces

- First define a mass of 1 kg (via a lump of platinum in Paris!)
- One "newton" is the force required to accelerate a body of one kilogram at 1 m/s^2

Text

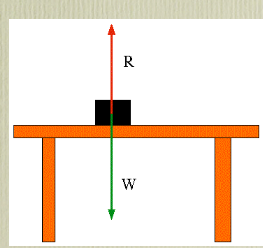
Third Law

- Action and reaction are equal and opposite
- An action is a force exerted by one object on another
- The reaction is the force exerted by the second on the first



Text

- Note that it is particularly easy to forget reaction forces:
- in this case, if you ignore the reaction force, the block would fall through the table.



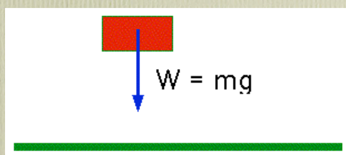
Text

Gravitation

- Most important (for us) is gravitational force, which gives rise to weight
- To a good approximation, all objects falling near the Earth's surface have the same acceleration
- $a = -g$ where $g = 9.8$ m/s^2
- How are grav. accn. and velocity connected?

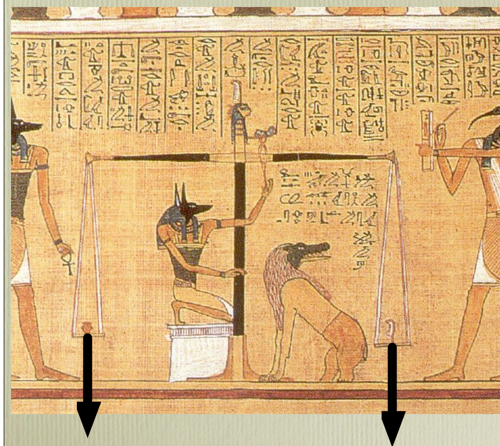
Text

- the gravitational force on an object is it’s weight
- W = mg
- In absolute terms a 1 kilogram mass has a weight of 9.8 newtons in the earth



Text

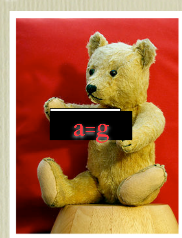
Usually compare objects with scales



A depiction of early balance scales in the Papyrus of Hunefer (dated to the 19th dynasty, ca. 1285 BC). The scene shows Anubis weighing the heart of Hunefer.

Wikipedia/ National Geographic

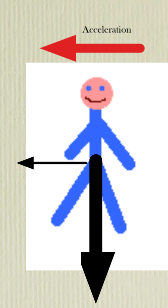
- Newton's 2nd. law shows that everything has the same acceleration in a gravitational field.
- F = ma (this is 2nd. law) = mg (this is weight)
- F = ma = mg ➡ ~~ma=mg~~



- Note:
- Mass of a body is the same anywhere in the universe
- Weight is the force on that body on the surface of the earth

Text

- Useful to compare forces to gravitation
- e.g. if your bus accelerates at 1 metre/s^2~ g/10, you need a horizontal force of ~1/10 mg
- Note: the force is required to accelerate you, so it’s in the same direction
- You *feel* a force that seems to throw you backwards



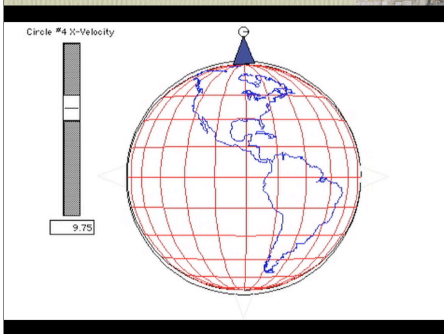
Why can’t we accelerate at (say) 100 times the rate?
Then we would get from one light to the next in 1/10 s!

Why can’t we accelerate at (say) 100 times the rate?
Then we would get from one light to the next in 1/10 s!

1. For long periods, can manage 1.5 g easily
2. Short periods 4g
3. Blackout at 10g
4. Squashed at 100g!

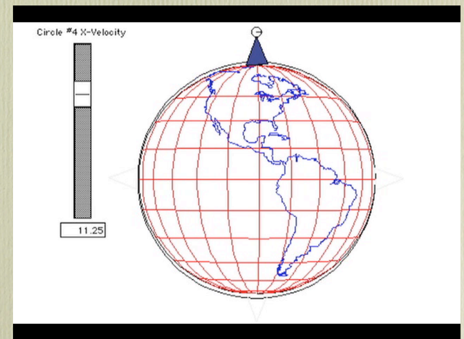
Text

Universal Gravitation

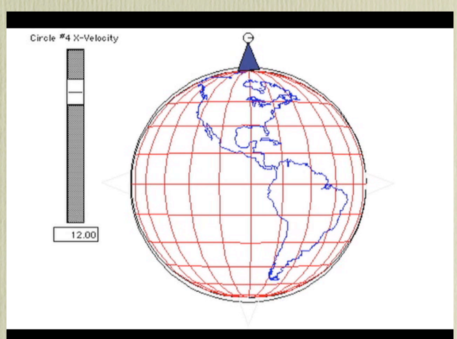


- How does the moon stay up?
- By falling!

- Faster



- and faster

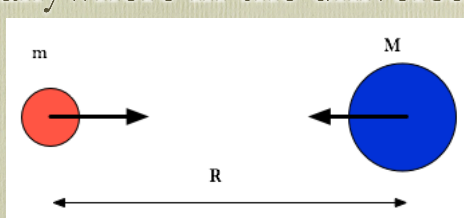


Warning: this slide contains an equation

- The extra step is to realise that any two bodies in the universe attract each other
- If they are mass M and mass m, separated by a distance r

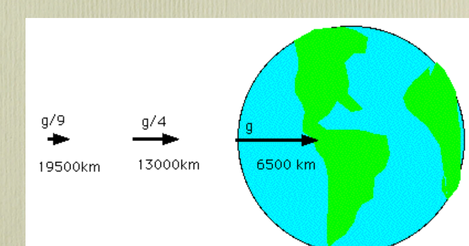
$$F = -\frac{GMm}{|r|^2}$$

Law of universal gravitation applies between any two bodies anywhere in the universe:



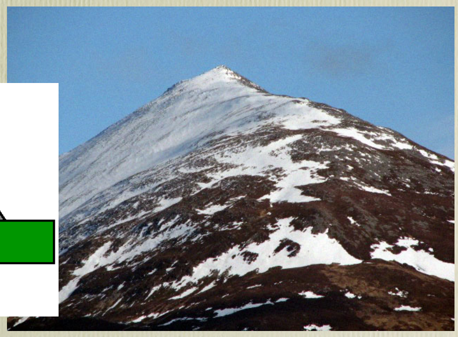
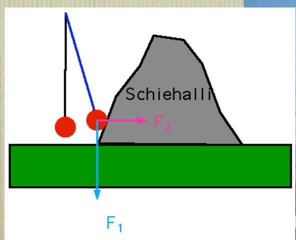
- Note that the forces are equal and opposite:
- you pull the earth as much as it pulls you!

Implies that grav. force gets weaker as we move away from



Even mountains!

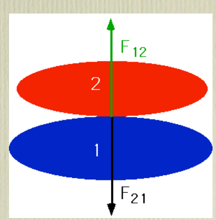
- First measurement was done with Schiehallion

- Weakening of gravity + falling of the moon
- ➟period of moon = 27 days = lunar month
- This was the first time that laws deduced on the Earth were seen to apply outside!

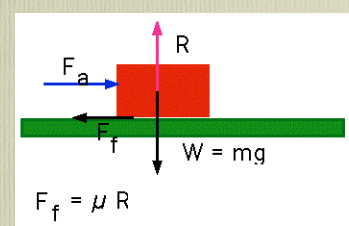
Need to worrry about a couple of other kinds of forces

- Contact forces
- Stop two bodies from sliding into each other



Friction

- A very complicated force



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1. Trevor Oberhammer
2. If a penny were dropped from the top of the CN tower could it severely or fatally injure a person on the sidewalk below?
3. This is a good question because there are many different areas of physics to consider such as force, resistance, momentum and collisions. Could a small, flat and light object such as a penny really gain enough speed and momentum from that height to seriously harm someone? Or would it just really sting and possibly leave a bruise?
4. My estimate for the difficulty of this question would be a 4.

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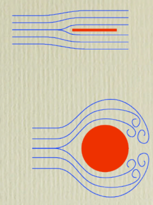
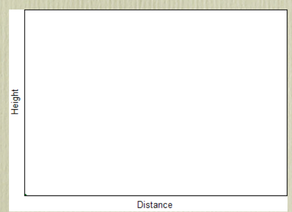
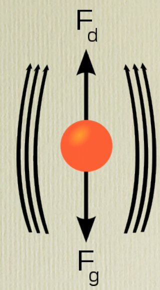
1. Katherine Grand
2. How can dust travel so slowly to be able to build up on both vertical and horizantal surfaces, yet in space build enough speed to damage to space shuttles and sattelies
3. I believe that this is an interesting question because dust is something that everyone deals with and is impossible to prevent its build up. Why then could something which appears to collect seemingly out of thin aircause damage to items which cost millions of dollars to create.
4. Scale: 3) I think it's hard, but I'd guess we could cover it in this course

- Air resistance
- increases with speed





- Terminal velocity
- we get a balance between the grav. force downwards
- $F_{grav} = mg$ (doesn't change)
- and air resistance (drag) upwards
- $F_{drag} = 1/2 CA\rho v^2$
- = 1/2 (Shape factor)×Area× density×speed×speed



Wikipedia

- Velocity will increase until these two balance
- Terminal velocity

$$v_t = \sqrt{\frac{2mg}{\rho AC}}$$

Mass of what is falling: e.g human m≈70kg

g=9.8 m/s²

$$v_t = \sqrt{\frac{2mg}{\rho AC}}$$

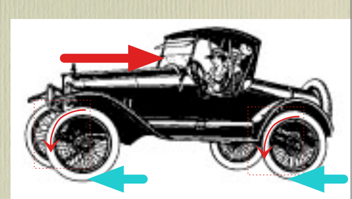
"Shape" usually C≈0.5

Density of air ρ≈1 kg/m³

Area: say A ≈1 m²

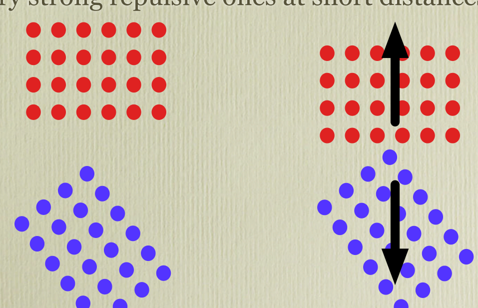
- For a human ~ 200 km/hr ~ 50 m/s
- For a coin ~ 20 km/hr ~ 4 m/s
- For a dust particle ~ 1 μ/s ~ ~ 1 mm/hr
- (1μ = micron = 1 millionth of a metre)
- In space, no air resistance to slow down dust

- A similar argument limits the top speed of cars.
- F_{drag} increases with square of speed
- $F_{rolling}$ (rolling resistance in tires & engine) roughly constant
- Driving force increases to a maximum
- (Better handled by energy arguments)

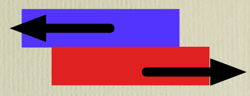


Text

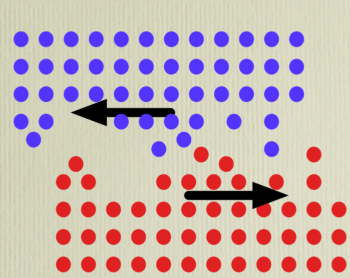
- Contact forces be understood at the atomic level
- Atoms have very weak interactions at large distances
- Very strong repulsive ones at short distances



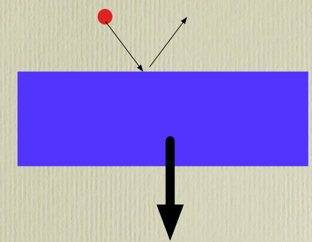
- Where do frictional forces come from?
- Surfaces seem smooth



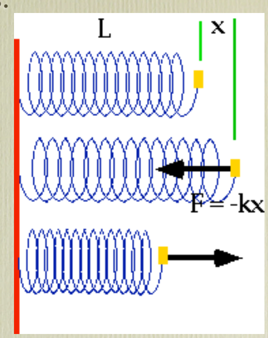
- at the atomic level, surface are rough and lock into each other



- Air resistance arises from collisions of air molecules with surface



- There a many other forces:
- e.g tension
- e.g. elastic
- e.g nuclear
- e.g electrical
- e.g magnetic



To finish up transport, we need to introduce energy