From last time

- Position, velocity, and acceleration
  - velocity = time rate of change of position
  - acceleration = time rate of change of velocity
  - Particularly useful concepts when
    - velocity is constant (undisturbed motion)
    - acceleration is constant (free falling object)

HW#1: Due

HW#2: Chapter 3: Conceptual: # 2, 26, 30, 40

Chapter 3: Problems: # 4, 6, 17

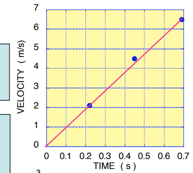
Galileo Uniform acceleration from rest

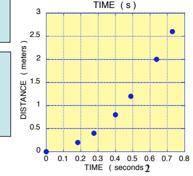
Acceleration = const = a = 9.8 m/s^2

Velocity = (acceleration)x(time) = at

Uniformly increasing velocity

Distance = (average vel)x(time) = $(1/2)at \times t = (1/2)at^2$





Falling object: constant acceleration

- Falling objects have constant acceleration.
- This is called the acceleration of gravity 9.8 m/s/s = 9.8 m/s^2
- But why does gravity result in a constant acceleration?
- Why is this acceleration independent of mass?

Tough questions

- These are difficult questions.
  Maybe not completely answered even now.
- But tied into a more basic question:
  - What causes acceleration?
  - Or, how do we get an object to move?

A hot topic in the 17th century.

Descartes was a major player in this.

Descartes' view…

- Motion and rest are primitive states of a body without need of further explanation.
- Bodies only change their state when acted upon by an external cause.

This is similar our concept of inertia

That a body, upon coming in contact with a stronger one, loses none of its motion; but that, upon coming in contact with a weaker one, it loses as much as it transfers to that weaker body

Momentum and it's conservation

Inertia

- Principle of inertia: object continues at constant velocity unless disturbed.
  - Need a disturbance to change the velocity.
- Inertia measures the degree to which an object at rest will stay at rest.
  - Objects with lots of inertia don't change motion as much as lighter objects subject to the same disturbance.
  - They are more difficult to accelerate

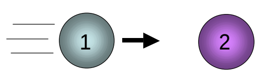
Quantifying Inertia: Mass and Momentum

- Same disturbance applied to different objects results in different velocities
  (e.g. hitting bowling ball and golf ball w/golf club).
- But the product
  mass × velocity
  is the same
  (e.g. for the bowling ball and the golf ball).
- Momentum = (mass)×(velocity)

Momentum conservation

- Can easily describe interactions of objects.
- The total momentum
  (sum of momenta of each object)
  of the system is always the same.
- We say that momentum is conserved.
  - Between the golf ball and the golf club
- Momentum can be transferred from one object to the other, but it does not disappear.

Momentum conservation: equal masses



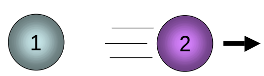
Before collision:

m = 1 kg
v = 1 m/s
p = mv = 1 kg-m/s

m =1 kg
v = 0 m/s
p=0

Total momentum =
1 kg-m/s+0 kg-m/s = 1 kg-m/s

After collision:

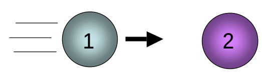


Total momentum =
0 kg-m/s+1 kg-m/s = 1 kg-m/s

m =1 kg
v = 0 m/s
p = 0 kg-m/s

m = 1 kg
v = 1 m/s
p = 1 kg-m/s

Another possibility



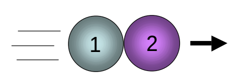
Before collision:

m = 1 kg
v = 1 m/s
p = mv = 1 kg-m/s

m =1 kg
v = 0 m/s
p=0

Total momentum before =
1 kg-m/s+0 kg-m/s = 1 kg-m/s

After collision: *balls stick together*



Total momentum after = 1 kg-m/s

m = 1 kg + 1 kg = 2 kg
v = 0.5 m/s
p = 1 kg-m/s

What about Newton?

- Like Galileo and Descartes, Newton has a law of inertia.
- **Newton's first law:**

Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it.

- The 'force' is the 'external disturbance' of Galileo and Descartes

Newtonian Forces

- Newton made a definition of force that described how momentum was transferred.
- He viewed it as a continuous process rather than the immediate transfer of Descartes and Galileo.
- This makes a connection with our intuitive understanding of 'force' as a push or a pull.

Newton's second law

- *The change in motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.*

(Momentum change)=(Applied force)×(time interval)

Change in momentum = Δp
Applied force = F
Time interval = Δt

$$\Delta p = F\,\Delta t$$

Impulse

- The momentum change is called an impulse when it occurs over a very short time.
- An impulse is a short 'disturbance' exerted on an object.
- It is equal to the momentum change of the object.
- It's units are the same as that of momentum
  - Units are kg-m/s
- Makes a connection between Descarte and Newton.

(change in momentum)=(Applied force)×(change in time)

$$\Rightarrow \frac{\text{change in momentum}}{\text{change in time}} = \text{applied force}$$

Momentum = (mass) × (velocity)
Change in momentum = (mass) × (change in velocity)

$$\Rightarrow \text{mass} \times \underbrace{\frac{\text{change in velocity}}{\text{change in time}}}_{\text{acceleration}} = \text{applied force}$$

F = ma

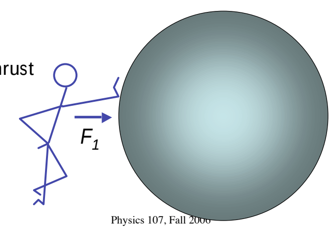
Newton's second law

Force = (mass) × (acceleration)

$$\text{acceleration} = \frac{\text{force}}{\text{mass}}$$

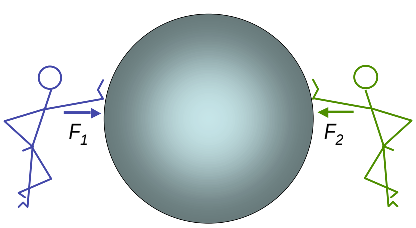
Force results in acceleration

- A body will **accelerate** (change its velocity) when another body exerts a force on it.
- This is also a change in momentum.
- But what is a force?
  - Push
  - Pull
  - Jet thrust



More than one force…

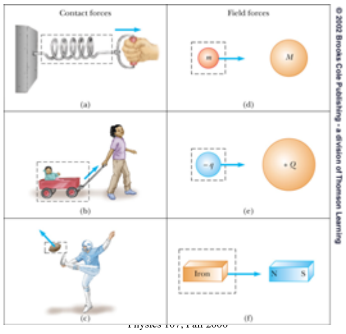
- Total force determines acceleration
- If F_1 and F_2 balance, acceleration is zero.



Back to falling bodies

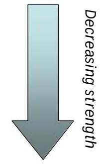
- A free-falling body moves with constant acceleration.
- Newton says that this means there is a constant force on the falling body.
- This is the gravitational force, and is directed downward.

Types of forces



The Four Forces

1. Strong nuclear force
2. Electromagnetic force
3. Weak nuclear force
4. Gravity



- Only gravity and electromagnetic forces are relevant in classical mechanics (motion of macroscopic objects).

Force and acceleration

- Larger force gives larger acceleration
- Directly proportional: $a \propto F$

- But clearly different bodies accelerate differently under the same force.
  - Heavier objects are harder to push.
  - Proportionality constant may depend on weight?

Inertia again

- But we already said that ***inertia*** characterizes a body’s tendency to retain its motion (I.e. to not change its velocity),
  We say a heavier object has more inertia.

- But inertia and weight are different
  - A body in space is weightless,
    but it still resists a push

Mass

- Define ***mass*** to be ‘the amount of inertia of an object’.
- Can also say mass characterizes the amount of matter in an object.
- Symbol for mass usually *m*
- Unit of mass is the kilogram (kg).

- Said before that $a \propto F$
- Find experimentally that $\text{Acceleration} = \dfrac{\text{Force}}{\text{Mass}}$

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

Force, weight, and mass

$$F = ma \Rightarrow F = (kg) \times (\text{m/s}^2)$$
$$= kg - m/s^2 \equiv \text{Newton}$$

- 1 Newton = force required to accelerate a 1 kg mass at 1 m/s^2.

But then what is weight?
—Weight is a force, measured in Newton’s
—It is the net force of gravity on a body.
—*F*=*mg*, *g*=*F*/m

Is ‘pounds’ really weight?

- In the English system (feet, pounds, seconds), pounds are a measure of ***force.***
- So it is correct to say my weight is 170 pounds.
- Then what is my mass?

$$m = \frac{F}{g} = \frac{170 lbs}{32 ft/s^2} = 5.3 \text{ slugs!!}$$

Momentum conservation

- We said before that an impressed force changes the momentum of an object.
- We also said that momentum is conserved.
- This means the momentum of the object applying the force must have decreased.
- According to Newton, there must be some force acting on that object to cause the momentum change.

Newton’s third law

- This is the basis for Newton’s third law:

To every action there is always opposed an equal reaction.

This is momentum conservation in the language of forces.