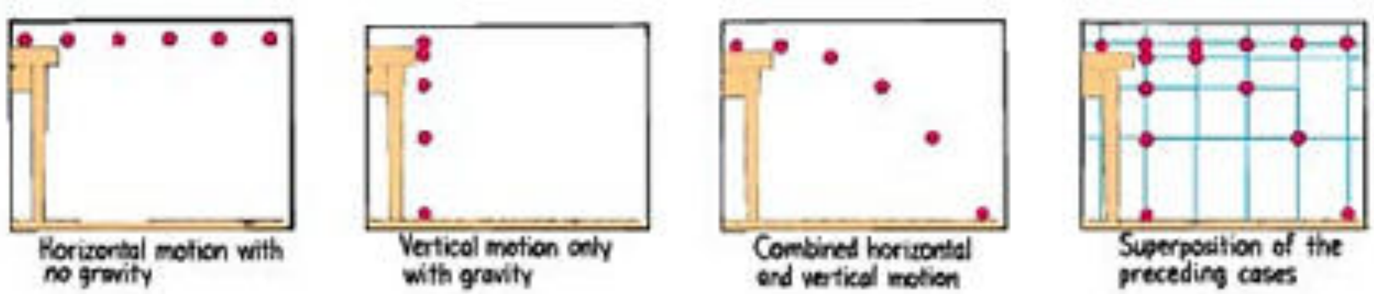
Announcements

- CAPA homework 3 due on Thursday Sept 20 at 10 AM
- Please register your iclicker through LON-CAPA
  - if you want to receive credit
  - only a few of you have not
  - first iclicker question today**: note: if I see anyone with two iclickers, I will take both of them**
- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM (except not Monday Sept 17)
  - Tues 12-3 PM
  - Wed 6-9 PM
  - Fri 10 AM-noon
- First exam Tuesday Oct. 2 10:20 AM this room
  - you may bring 1 sheet of hand-written notes; no xeroxing
- Final Exam Tuesday Dec 11 7:45-9:45 AM

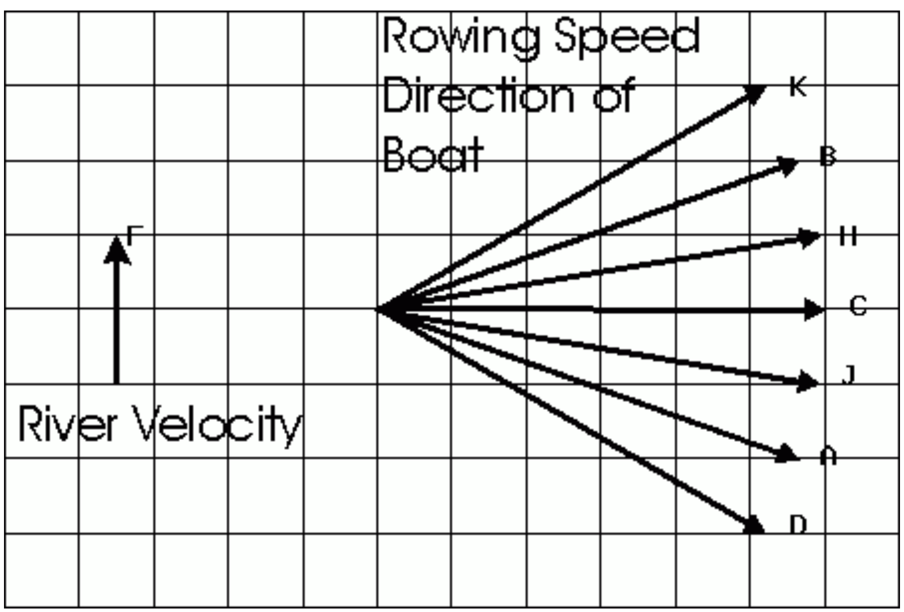
Vertical and horizontal motions

- When both vertical and horizontal motions are present, they can be treated completely independently
- For example, below is shown a ball rolling off of a table with a constant horizontal velocity
- The constant horizontal velocity continues (ignoring any air resistance) while there is a vertical acceleration due to gravity



LON-CAPA problem

- A river is to be crossed by a boy using a row boat
- He has the choice of rowing in directions A,B, C, D,…; in any direction, he rows at a constant speed with respect to the water
- So this is a vector addition problem



- What direction should he row to cross the river in the shortest time?

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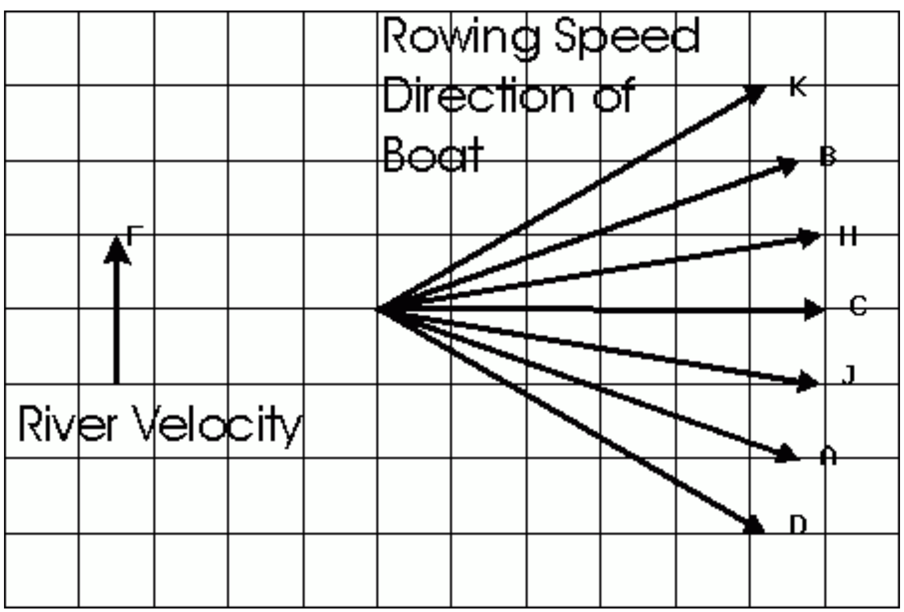

- What direction should he row to cross the river in the shortest time?
- C, because this gives him the maximum speed transverse to the river
- In this case, he doesn't care where he ends up (carried downstream by the current)

LON-CAPA problem

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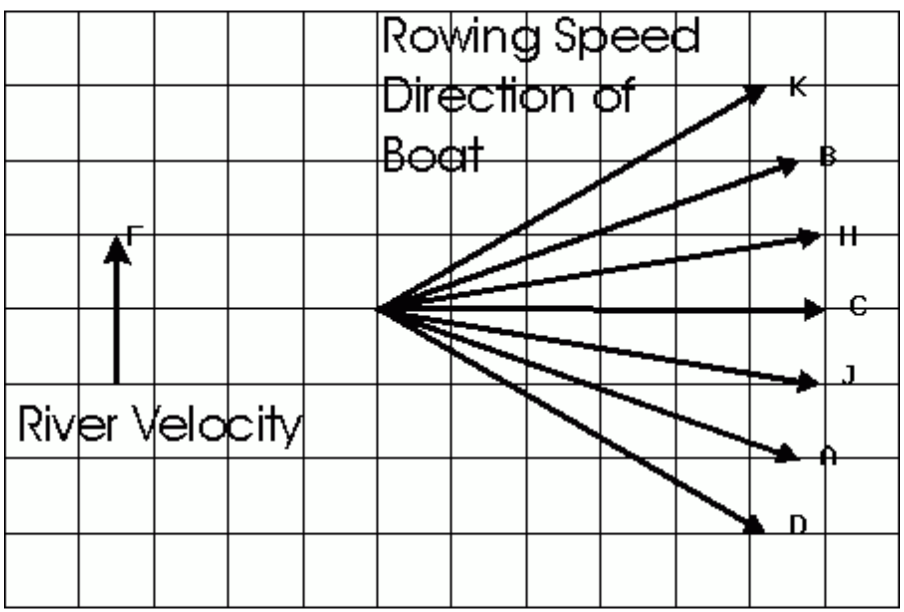
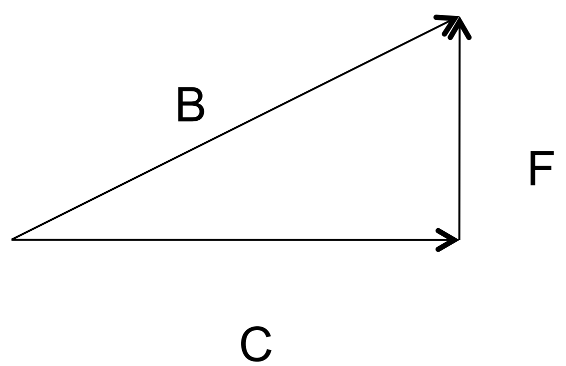
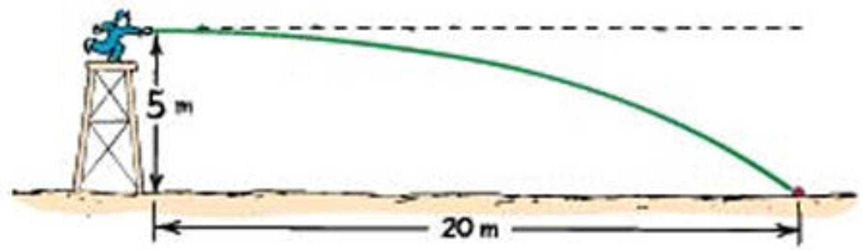
- If he rows with velocity in the direction of C, where does he end up?
- Add two vectors



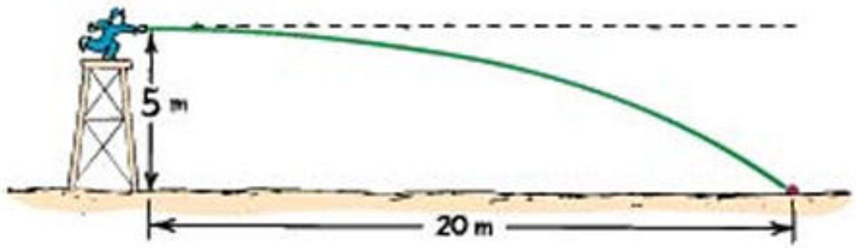


Back to projectile motion

- How fast is the ball thrown?
- How would you approach the problem?



- How fast is the ball thrown?
- How would you approac the problem?
- Separate into horizontal and vertical motions
- How long does it take for the ball to drop 5 m?
- During that time it has travelled 20 m horizontally



- How fast is the ball thrown?
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- **How long does it take for the ball to drop 5 m?**
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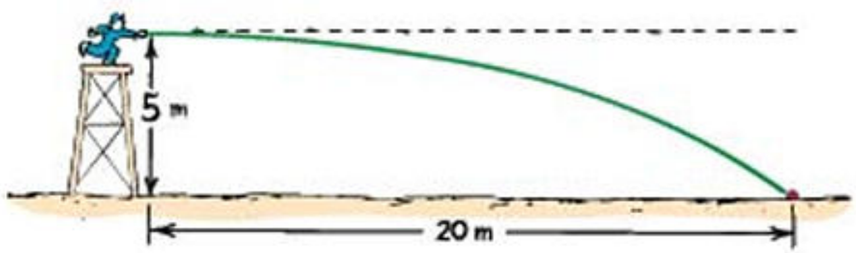

$$y = y_o + v_o^y t - \frac{1}{2} g t^2$$

$$0 = 5m - \frac{1}{2}(9.83 m/s^2) t^2$$

$$t^2 = \frac{10m}{9.83 m/s^2}$$

$$t = 1.01 s$$

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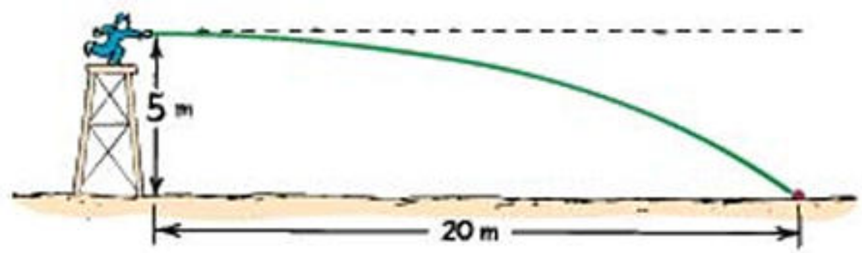


$$t = 1.01s$$

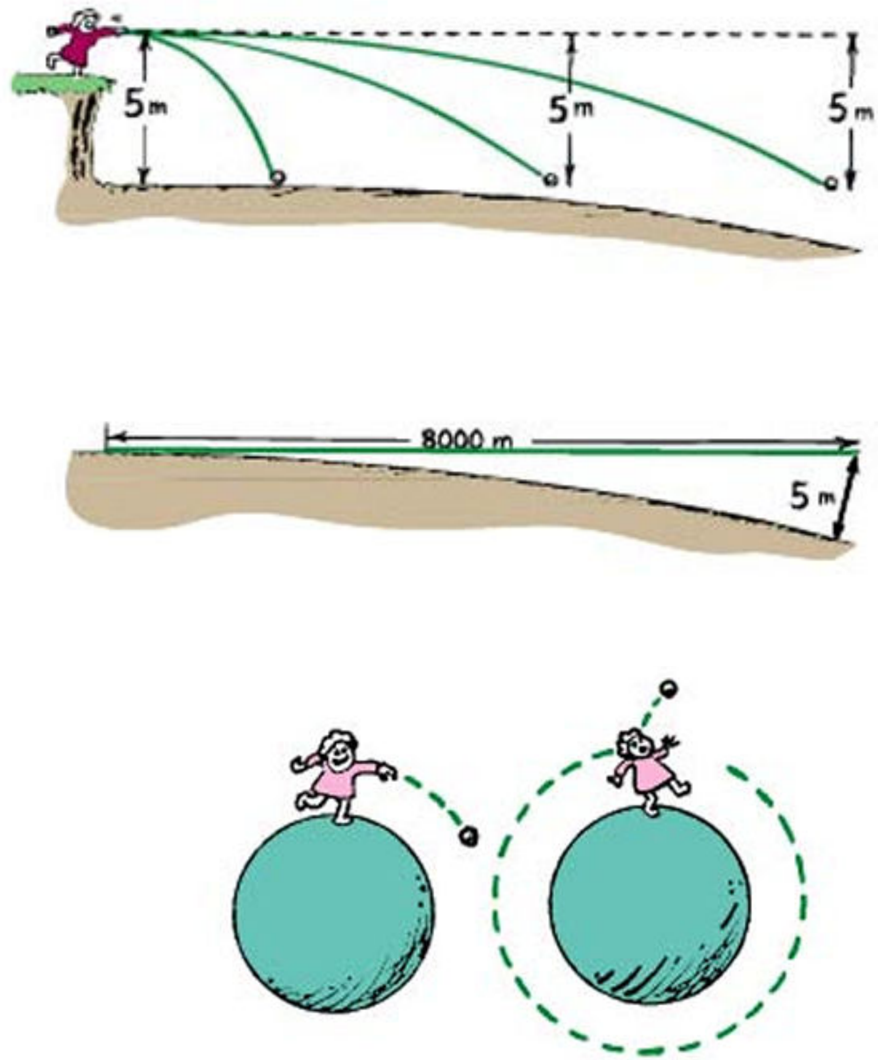
$$x = x_o + v_o^x t$$

$$20m = v_o^x (1.01s)$$

$$v_o^x = 19.8m/s$$

Satellites

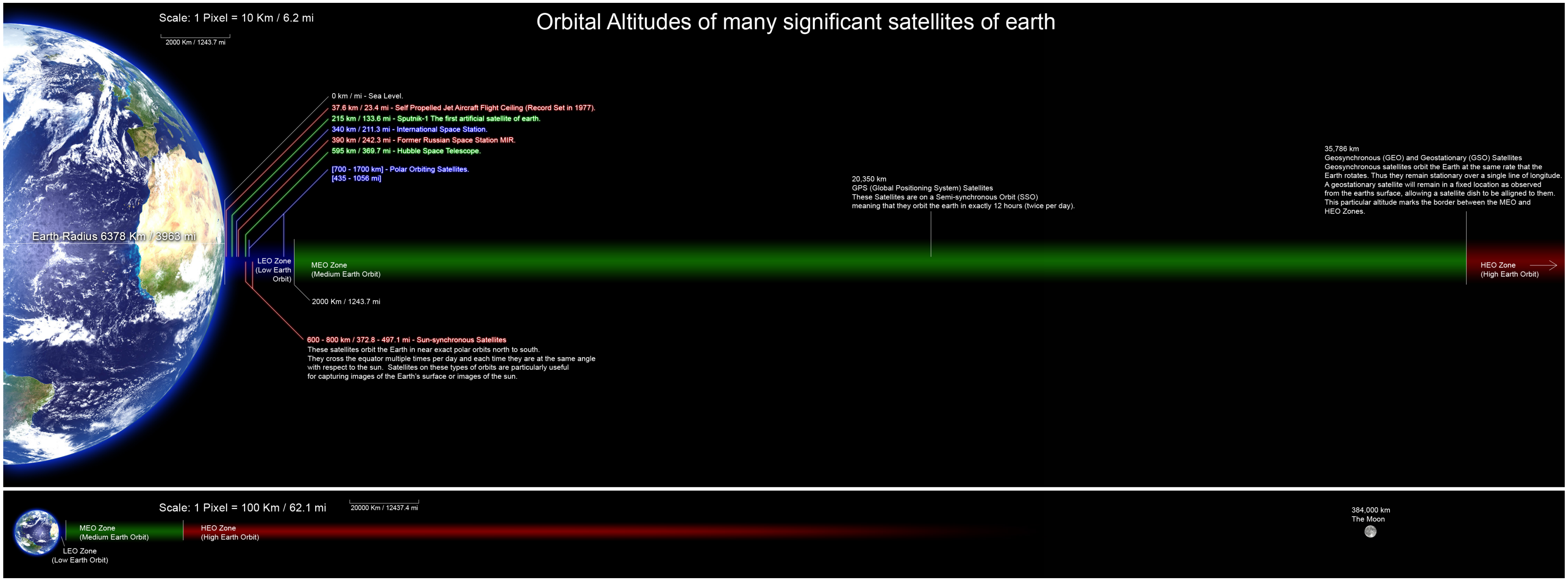
- What happens as you throw the ball harder and harder?
- It goes farther before it hits the Earth's surface
- The Earth's surface falls off about 5 m every 8000 m
- If you can throw a ball hard enough so that it travels 8000 m in the 1 second it takes to fall 5 m, then it will keep on falling around the surface of the Earth
    - 8 km/s
    - or 29,000 km/hour
    - orbital velocity



Orbits

Earth orbits

orbit	center-to-center distance	altitude above the Earth's surface	speed	Orbital period
Earth's surface (for comparison)	6,400 km	0 km	7.89 km/s (17,650 mph)	—
Low Earth orbit	6,600 to 8,400 km	200 to 2,000 km	circular orbit: 7.8 to 6.9 km/s (17,450 mph to 15,430 mph) respectively elliptic orbit: 8.2 to 6.5 km/s respectively	89 to 128 min
Molniya orbit	6,900 to 46,300 km	500 to 39,900 km	10.0 to 1.5 km/s (22,370 mph to 3,335 mph) respectively	11 h 58 min
GEO	42,000 km	35,786 km	3.1 km/s (6,935 mph)	23 h 56 min
Orbit of the Moon	363,000 to 406,000 km	357,000 to 399,000 km	1.08 to 0.97 km/s (2,416 to 2,170 mph) respectively	27.3 days



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Kepler's 3rd law

The **square** of the period of the orbit of a planet (or moon) is proportional to the **cube** of the radius (semi-major axis), and is inversely proportional to the mass of the object around which it is orbiting.

period

radius

$$\left(\frac{P}{2\pi}\right)^2 = \frac{a^3}{GM_{\cancel{sun}}}$$

Earth

Clicker question

- A planet is discovered in another solar system which has the same diameter for its orbit around its star as the Earth does around the Sun. Their star, however, has a mass of four times that of our Sun. How long does it take this new planet to travel around its star?

a) 1 year
b) 2 years
c) ½ year
d) ¼ year
e) not enough information to determine

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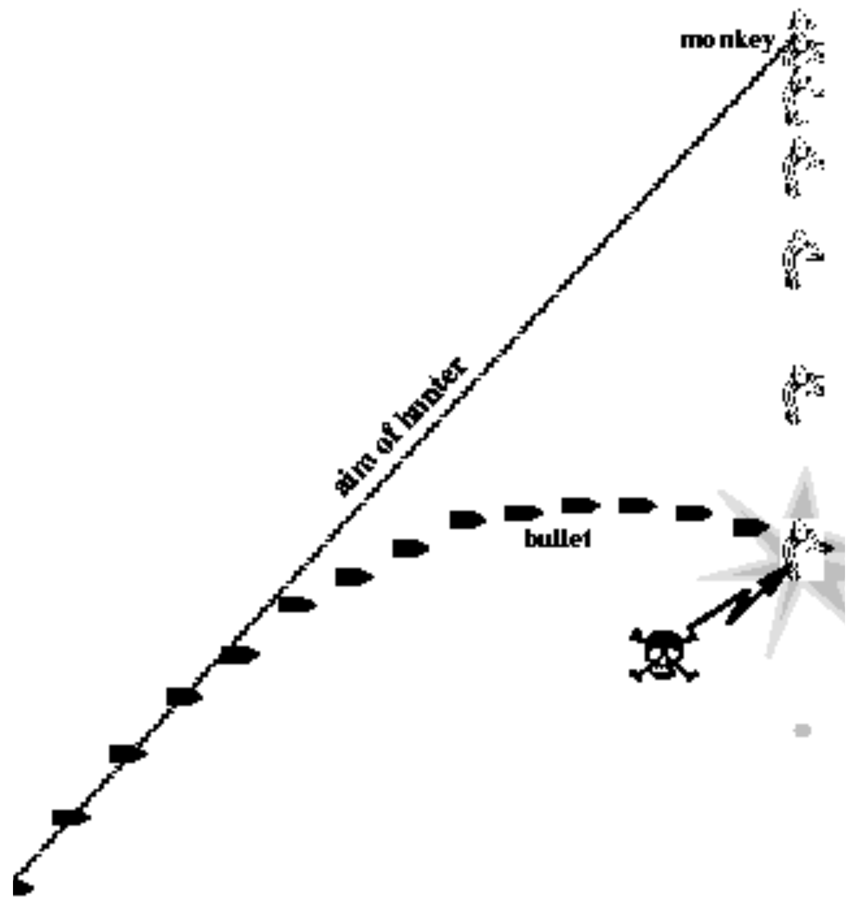
Extrasolar planets

- To date, over 660 of them have been discovered
- Most are Jupiter-size are larger
  - they're the easiest to discover
- Some appear to be Earth-size
- And some are the right distance from their star to support life

‘Shoot the monkey’

- We said that the vertical and horizontal motions for projectiles were independent
- Neglecting air resistance, there is an acceleration only in the vertical direction (due to gravity) and it is the same regardless of whether there is horizontal motion or not
- Suppose a hunter is aiming at a monkey hanging in a tree
- The monkey lets go at the same instant that the hunter pulls the trigger
- Does the monkey get hit?
- Yes, if the initial aim is correct, because the monkey and the bullet have the same acceleration

Figure 4.5: Shoot the ``monkey'': an illustration o
motion in two dimensions.

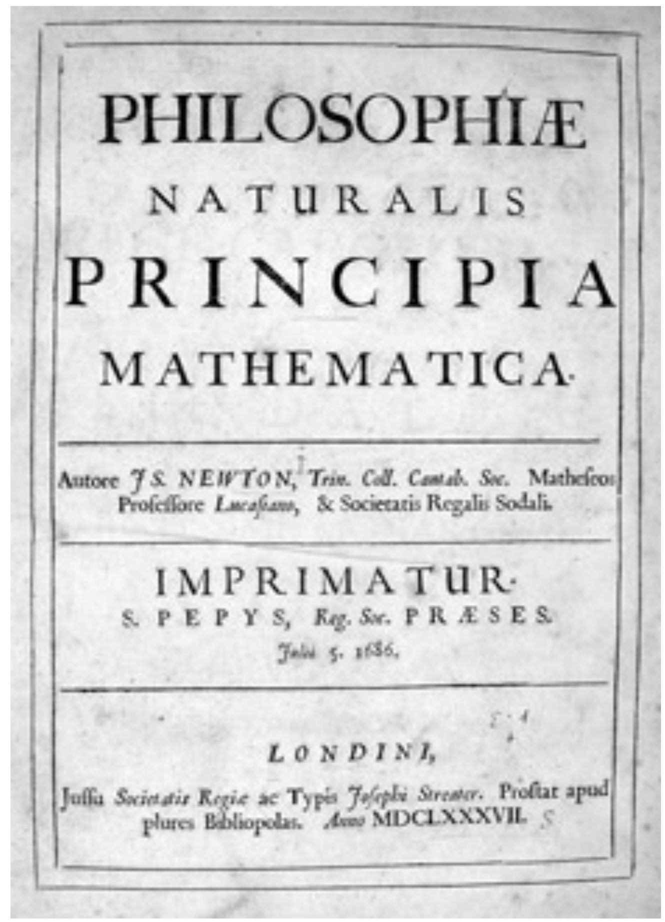


…no actual monkeys will be harmed in this demonstration

Newtonian worldview

- During the 16th and 17th centuries, the new sun-centered astronomy and inertial physics ushered in a new philosophical view
  - Newtonian worldview
- Pre-Newtonian worldview combined medieval Christianity, the Earth-centered astronomy of the Greeks and Aristotle's physics
- Newtonian worldview swept away the notion that the Earth is special
  - not by chance that the stirrings of religious and political freedom began at this time
- The universe is a finely-tuned clock, whose operating principles are the laws of nature and whose parts are atoms
  - this means that the universe is predictable; with Newton's laws and enough information you can predict future behaviors

- Published in 1687, detailing his laws of motion, the universal law of gravitation and much more
- Made possible a quantitative understanding of the universe


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore JS. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

Momentum and energy

- Momentum = inertia in motion or, more specifically, the product of the mass of an object and its velocity
  - momentum = mass X velocity
  - $\vec{p}=m\vec{v}$
  - most of the time, we’re not concerned with the direction of the motion, so we can write p=mv

This tanker has a large momentum, mostly because of m.

This car had a large momentum, mostly because of v.

Impulse

- If the momentum of an object changes, then either the mass changes, the velocity changes or both change
- If it's the velocity that changes, then the object experiences an acceleration
- That acceleration must be caused by an external force
- The length of time that a force is applied is important
  - a force applied for a longer time creates a larger change of momentum
- We call the product of the force and the length of time of the interaction, the impulse
  - impulse= force X time=Ft

Impulse

- Impulse = Ft
- but

$$F = ma = m\frac{\Delta v}{\Delta t}$$

- Rearrange

$$\frac{F}{m} = \frac{\Delta v}{\Delta t}$$

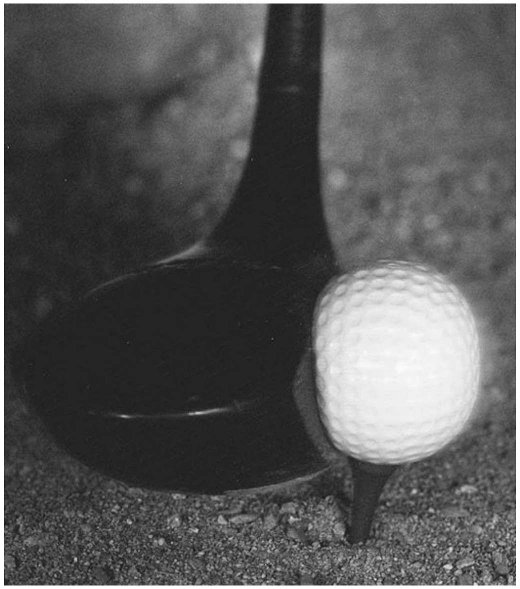
- And re-write as

$$F\Delta t = m\Delta v$$

$$Ft = \Delta(mv) = \Delta p$$

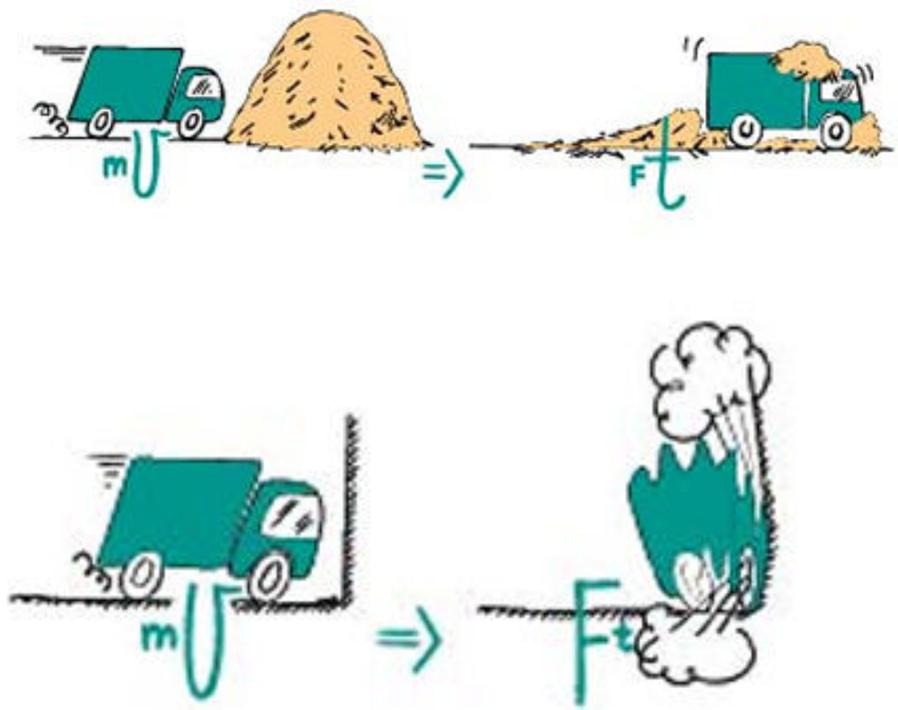
- Since the force may change with time in the interactions we're considering, we'll let F stand for the average force

- The impulse, or product of force and time equals the change in momentum



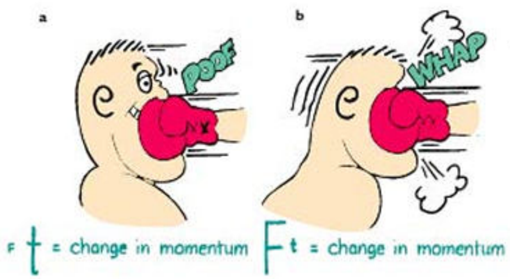
Impulse

- You have to bring your car to a stop
- You have a choice of running into a haystack or running into a wall
- You choose the haystack even though the change in momentum, the impulse, is the same in both cases
- By increasing the interaction time, you can decrease the average force, even though Δp is the same for both circumstances



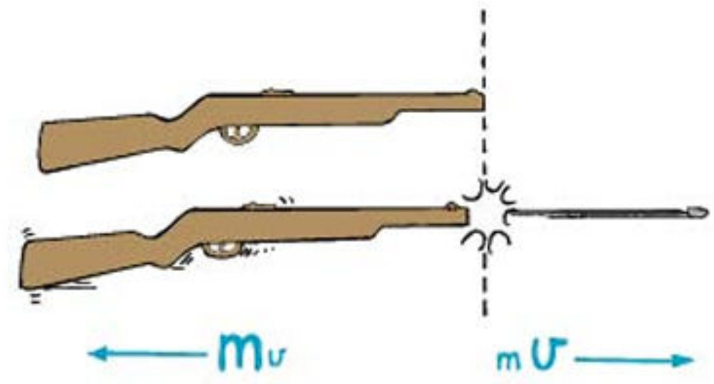
Interaction time

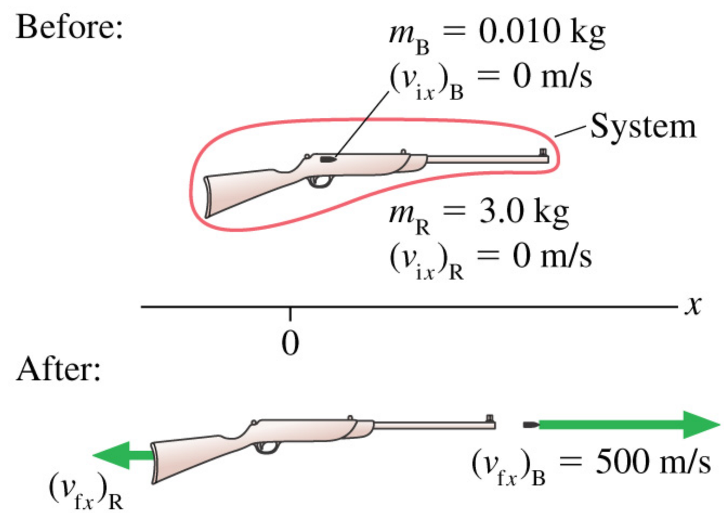
- Boxers and bungee jumpers know the same physics lesson
- Increase the interaction time to lessen the force
- Whereas karate experts know to try to decrease the interaction time to have the greatest effect



Conservation of momentum

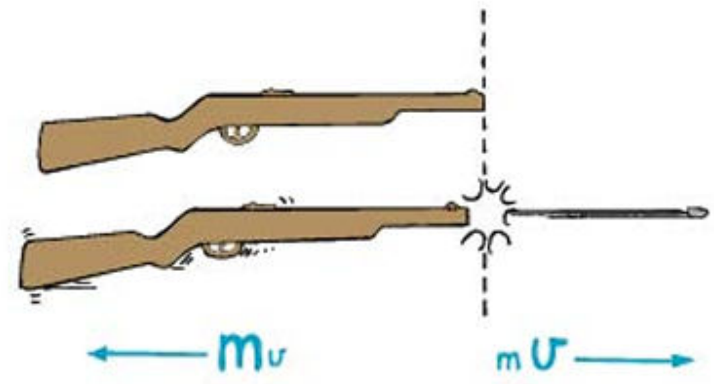
- Let's consider the rifle firing a bullet
- Only an impulse external to the system can change the total momentum of a system
- So the total momentum of the rifle + bullet system is conserved
- So the momentum of the bullet equals the recoil momentum of the rifle
  - Mv = mV
- Since M >> m, V >> v
- But $P_{rifle}=P_{bullet}$

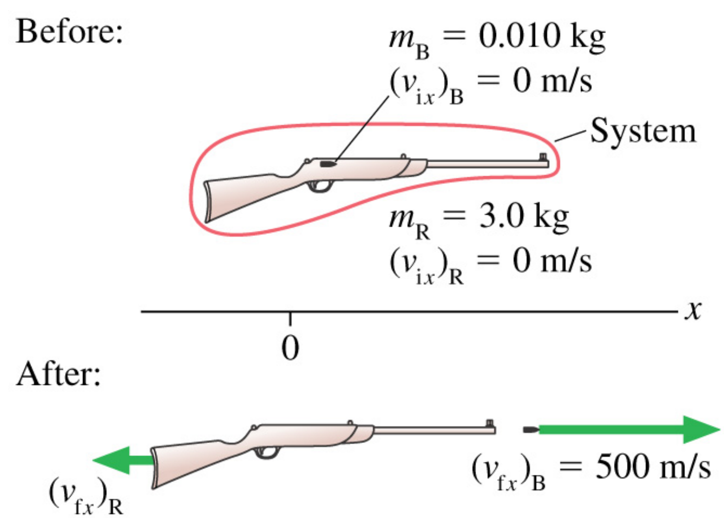




Conservation of momentum

- What is the final velocity of the rifle?
- m_{rifle}*v_{rifle}=m_{bullet}*v_{bullet}
- v_{rifle}=(m_{bullet}*v_{bullet})/m_{rifle}
- v_{rifle}=(0.01kg*500m/s)/3.0kg
- v_{rifle}=1.67 m/s

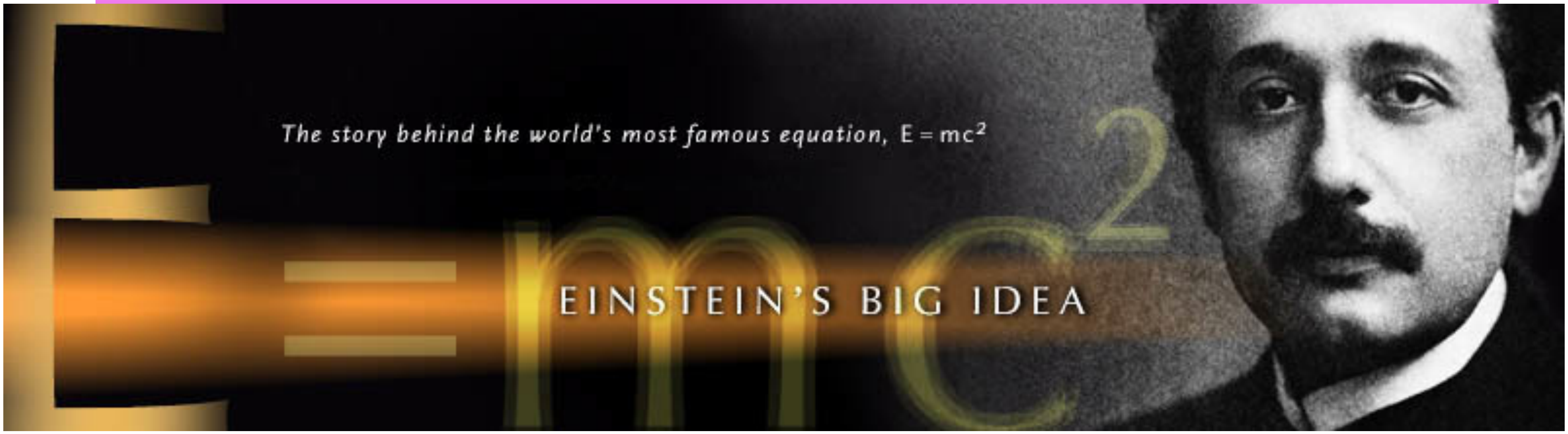




Conservation laws

- A conservation law specifies that certain quantities in a system remain precisely constant, regardless of what changes may occur within the system
- Momentum is unchanged, i.e. is conserved
- Energy is also conserved as is
  - mass (although we'll see the connection between mass and energy when we discuss relativity)
  - angular momentum
  - electric charge
  - some subatomic properties that we'll study later in the course

Einstein's Big Idea



- Nova program about the story of $E=mc^2$
- But they go back to the origins of our modern understanding about energy including discussions of scientists like Michael Faraday, Antoine Lavoisier and Emilie du Chatelet

Conservation of mass

- Energy is conserved
- Lavoisier, along with his wife, proved that mass was conserved in chemical reactions
- “Einstein’s Big Idea”