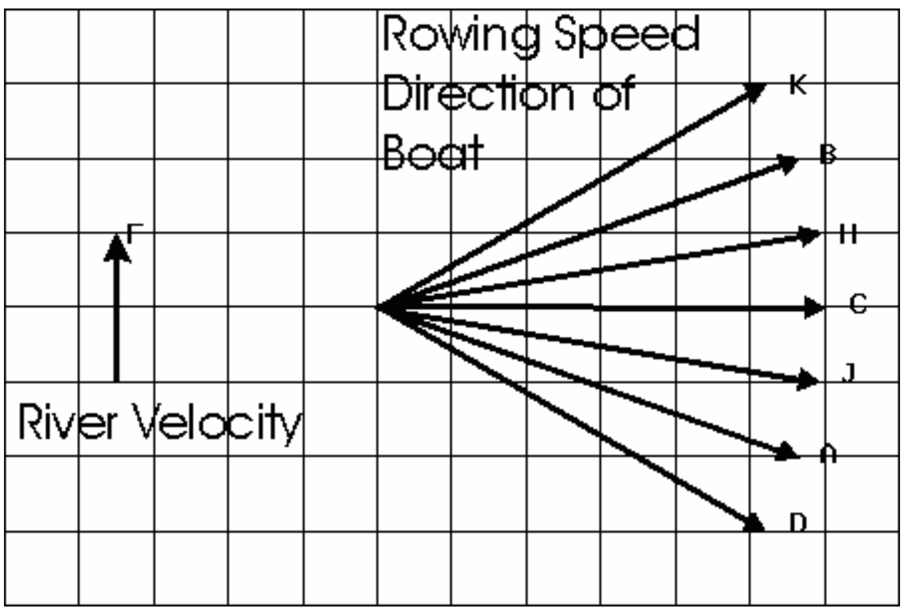
- LON-CAPA #4 and Mastering Physics Chapter 7 due next Tuesday
  - help room hours (Strosacker Help Room, 1248 BPS):
    M: 5-8 PM
    W: 5-8 PM
    F: 2-6 PM
- Register for Mastering Physics
  - >95% of you have
- Register your iclicker on LON-CAPA
  - >98% of you have
  - I'll post the scores up to last Thursday's lecture on the web
- First exam: Feb 6 in Life Sciences A133

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

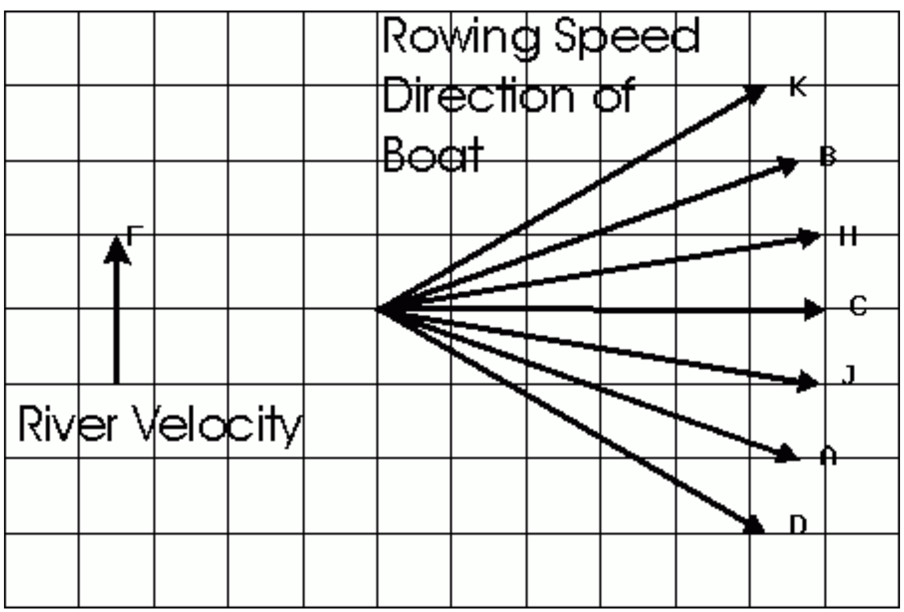


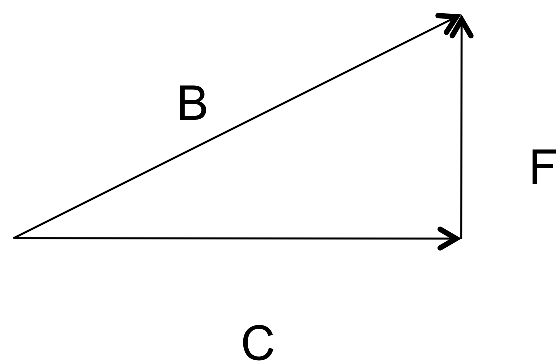
- If he rows with velocity in the direction of C, where does he end up?

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

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





Universal law of gravitation

- Newton's law of gravity describes gravitational forces on the surface of the Earth, and off the surface of the Earth

$$F = G\frac{m_1 m_2}{d^2}$$

- A tremendous advance; the law of gravity, along with the 3 laws of motion, meant that the motion of planets, and motions on Earth, could be completely described within a mathematical framework
- Some philosophers started to talk about a 'clockwork universe'
- But how is Newton's law of gravity incomplete?

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- But how is Newton's law of gravity incomplete?

- Newton assumed (because he had no evidence one way or the other) that the force of gravity was transmitted instantaneously in a manner which could not be described
  - 'action-at-a-distance'
- It was left to Einstein (over 200 years later) to describe gravity as being due to the curvature of space
  - and that gravitational disturbances travelled at the speed of light

iclicker question

- The gravitational constant G in Newton’s law of gravity

a) Produces the correct units of force in Newton’s equation
b) Indicates the strength of gravity
c) Changes the proportion form of the law of gravity to an exact equatioin
d) All of these
e) None of these

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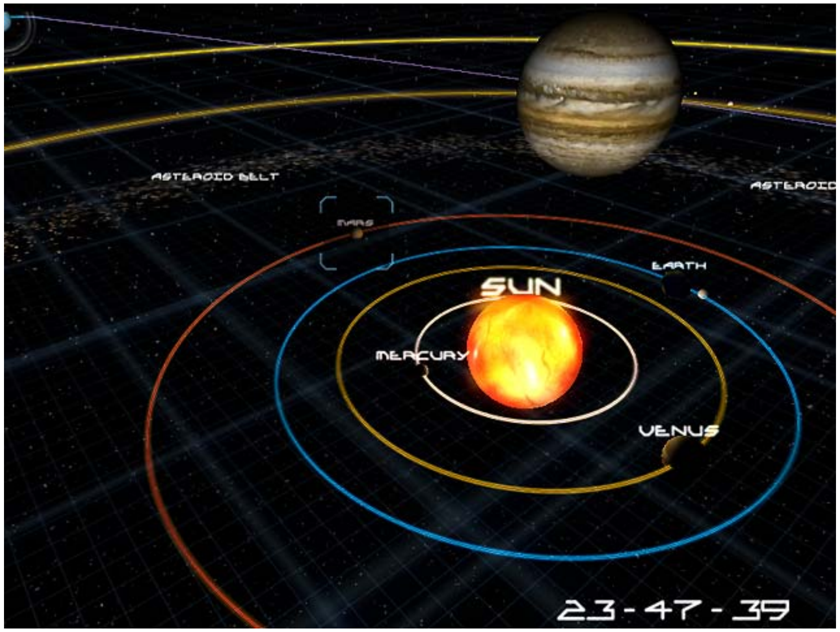
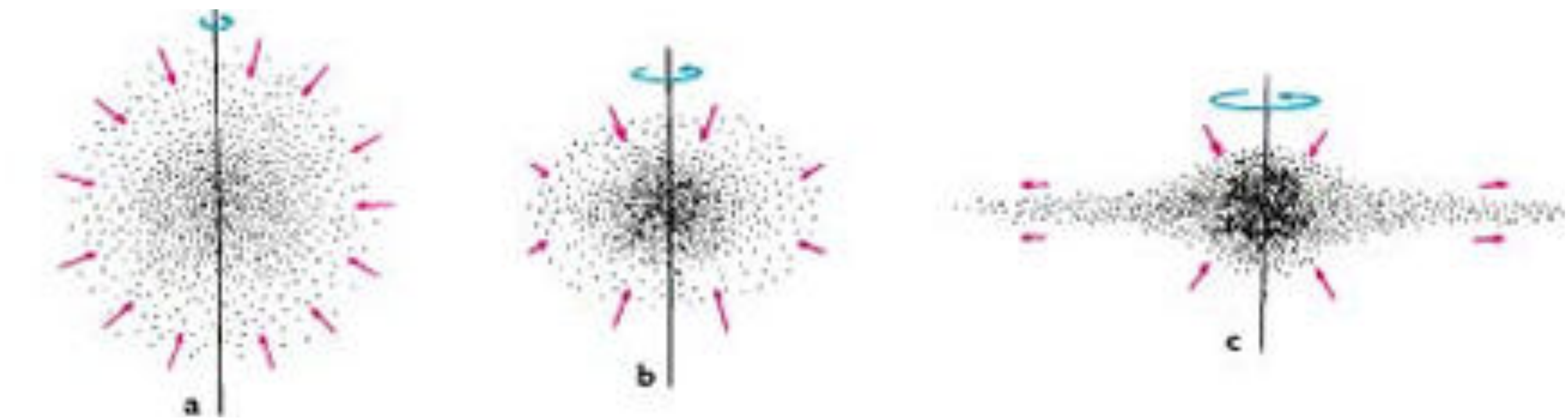
Gravity

- What's responsible for keeping the solar system together?
  - gravity
- What would happen if the sun were replaced by a black hole of the same mass?
  - nothing, except that it would get dark
  - the gravitational force of the sun already acts as if its originating from a point in the center of the sun
- What's responsible for keeping the Milky Way together?
  - gravity, except there's not enough visible matter
  - most of the universe appears to be composed of *dark matter*



Origin of the solar system

- Remember our sun was created after the universe was about 10 billion years old
- A slightly rotating ball of interstellar gas (enriched in heavy elements due to earlier supernovae) contracts due to gravitational attraction and speeds up to conserve angular momentum
- The increased momentum causes them to sweep in wider paths around the rotational access, producing an overall disk shape
- The planets condense out of eddies in the cooling disk

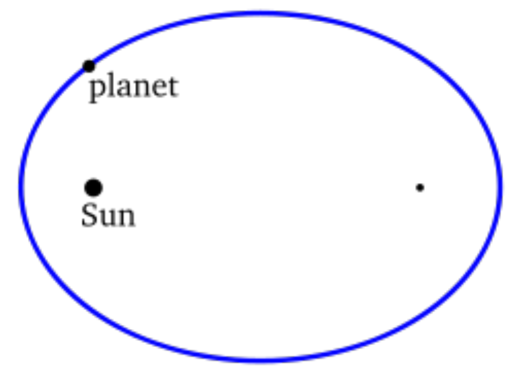


Johannes Kepler

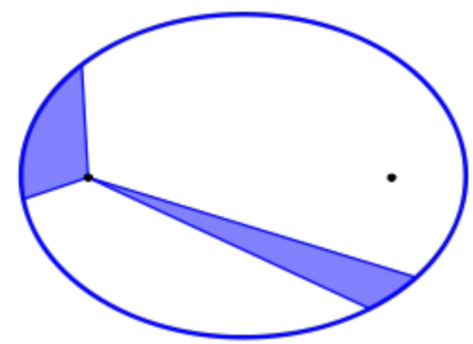
- 1571-1630
- He took the detailed observations of Tycho Brahe on the motions of the planets and was able to formulate 3 laws that describe the motions of the planets

Kepler's 3 laws

- Every planet has an elliptical orbit with the Sun at one focus of the ellipse



- A line joining the planet and the Sun sweeps out equal areas in equal times
  - so the planet must move fastest when it's closest to the Sun



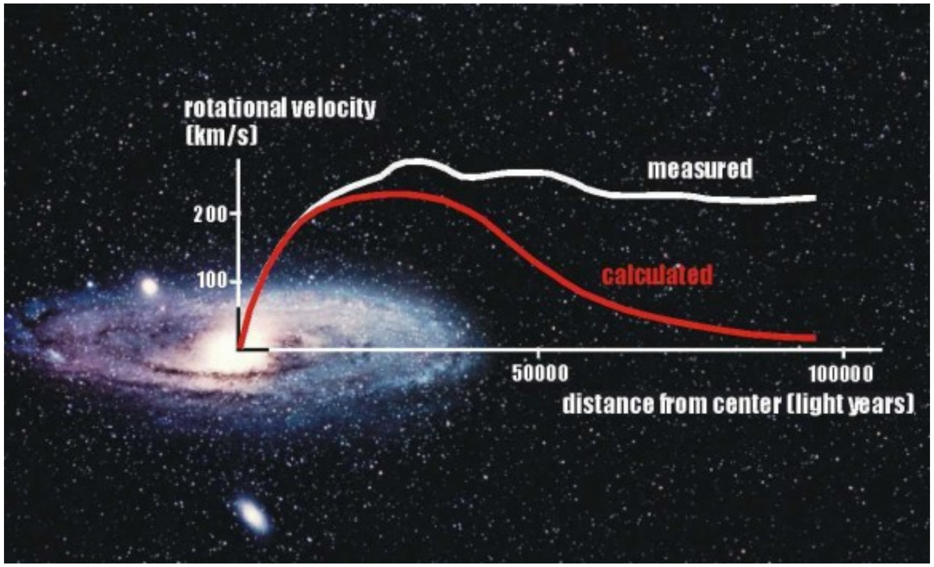
- The square of the period of the orbit of a planet is proportional to the cube of the radius (semi-major axis)

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

Empirical observations from Kepler; can be derived using Newton's law of gravitation

Rotation of the galaxy and dark matter

- Remember earlier I said that you would expect stars further from the center of the galaxy to rotate more slowly than ones at the center
- The fact that this does not happen is evidence of the presence of dark matter around our galaxy (10X as much dark matter as regular matter)



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

Empirical observations from Kepler; can be derived using Newton's law of gravitation

Planets

Table of the largest objects in the Solar System - Wikipedia, the free encyclopedia

http://en.wikipedia.org/wiki/Attributes_of_the_largest_solar_system_bodies

Planets

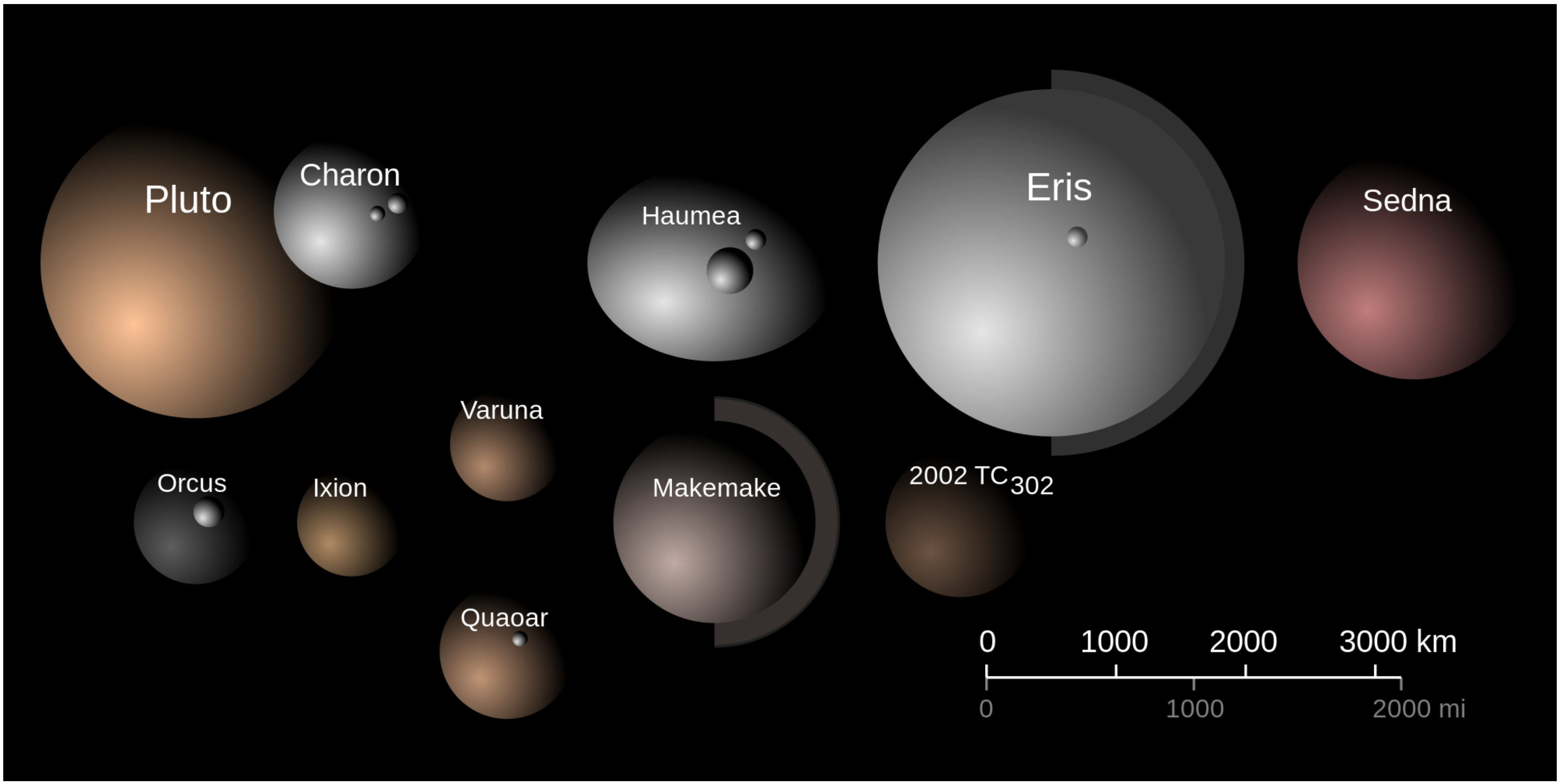
		Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Astronomical symbol		☿	♀	⊕	♂	♃	♄	⛢	♆
Mean distance from Sun	km	57,909,175	108,208,930	149,597,870	227,936,640	778,412,010	1,426,725,400	2,870,972,200	4,498,252,900
	AU	0.38709893	0.72333199	1	1.52366231	5.20336301	9.53707032	19.19126393	30.06896348
Mean radius	km	2,439.64	6,051.59	6,378.15	3,397.00	71,492.68	60,267.14	25,557.25	24,766.36
	:E[1]	0.3825	0.9488	1	0.53226	11.209	9.449	4.007	3.883
Surface area	km²	75,000,000	460,000,000	510,000,000	140,000,000	64,000,000,000	44,000,000,000	8,100,000,000	7,700,000,000
	:E[1]	0.1471	0.9010	1	0.2745	125.5	86.27	15.88	15.10
Volume	km^3	6.083×10^{10}	9.28×10^{11}	1.083×10^{12}	1.6318×10^{11}	1.431×10^{15}	8.27×10^{14}	6.834×10^{13}	6.254×10^{13}
	:E[1]	0.056	0.87	1	0.151	1,321.3	763.59	63.086	57.74
Mass	kg	3.302×10^{23}	4.8690×10^{24}	5.9742×10^{24}	6.4191×10^{23}	1.8987×10^{27}	5.6851×10^{26}	8.6849×10^{25}	1.0244×10^{26}
	:E[1]	0.055	0.815	1	0.107	318	95	14	17
Density	g/cm^3	5.43	5.24	5.515	3.940	1.33	0.70	1.30	1.76
Equatorial gravity	m/s^2	3.70	8.87	9.81	3.71	23.12	8.96	8.69	11.00
Escape velocity	km/s	4.25	10.36	11.18	5.02	59.54	35.49	21.29	23.71
Rotation period	days[2]	58.646225	-243.0187[3]	0.99726968	1.02595675	0.41354	0.44401	-0.71833[3]	0.67125
Orbital period	years[2]	0.2408467	0.61519726	1.0000174	1.8808476	11.862615	29.447498	84.016846	164.79132
Mean orbital speed	km/s	47.8725	35.0214	29.7859	24.1309	13.0697	9.6724	6.8352	5.4778
Eccentricity		0.20563069	0.00677323	0.01671022	0.09341233	0.04839266	0.05415060	0.04716771	0.00858587
Inclination	deg.	7.00487	3.39471	0.00005	1.85061	1.30530	2.48446	0.76986	1.76917
Axial tilt[4]	deg.	0.0	177.3	23.45	25.19	3.12	26.73	97.86	29.58
Mean surface temp.	K	440	730	288-293	186-268	152	134 [5]	76 [5]	72 [5]
Mean air temp.[6]	K			288		165	135	76	73
Atmospheric composition		He Na^+ P^+	CO_2 N_2	N_2 O_2	CO_2 N_2 Ar	H_2 He	H_2 He	H_2 He CH_4	H_2 He CH_4
Number of known moons		0	0	1	2	63	60	27	13
Rings?		No	No	No	No	Yes	Yes	Yes	Yes
Planetary discriminant[7]		9.1×10^4	1.35×10^6	1.7×10^6	1.8×10^5	6.25×10^5	1.9×10^5	2.9×10^4	2.4×10^4

Dwarf planets

	Ceres	Pluto	Makemake	Eris

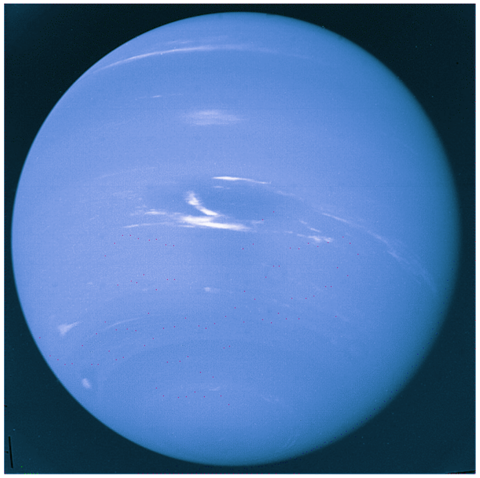
Dwarf planets

…from the outer reaches of the solar system; they take 100's of years (or more) to orbit the sun



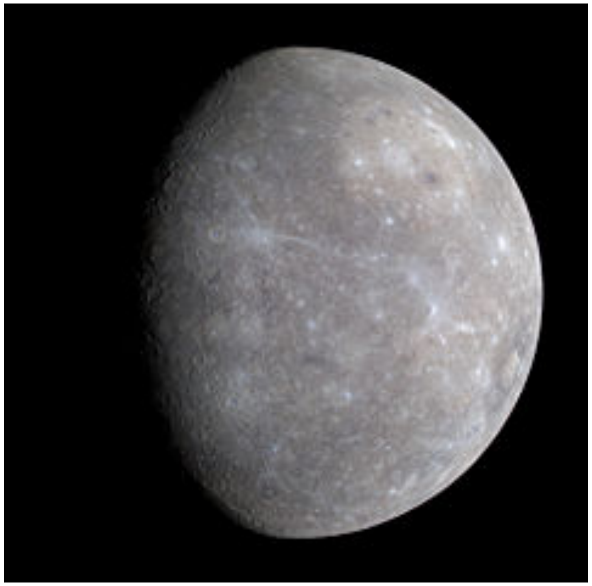
Uranus

- First planet discovered in modern times
  - not visible to naked eye
- The largest gravitational force in the solar system is due to the Sun (most of the mass)
- But the other planets in the Solar System tug on each other and cause the planets to wobble in their orbits
- If you calculate the effects of all of the other planets on Uranus' wobble, it's not enough
- Either the universal law of gravitation doesn't work at these large distances or there's an 8th planet
- There is an 8th planet (Neptune) and it was where they calculated it should be



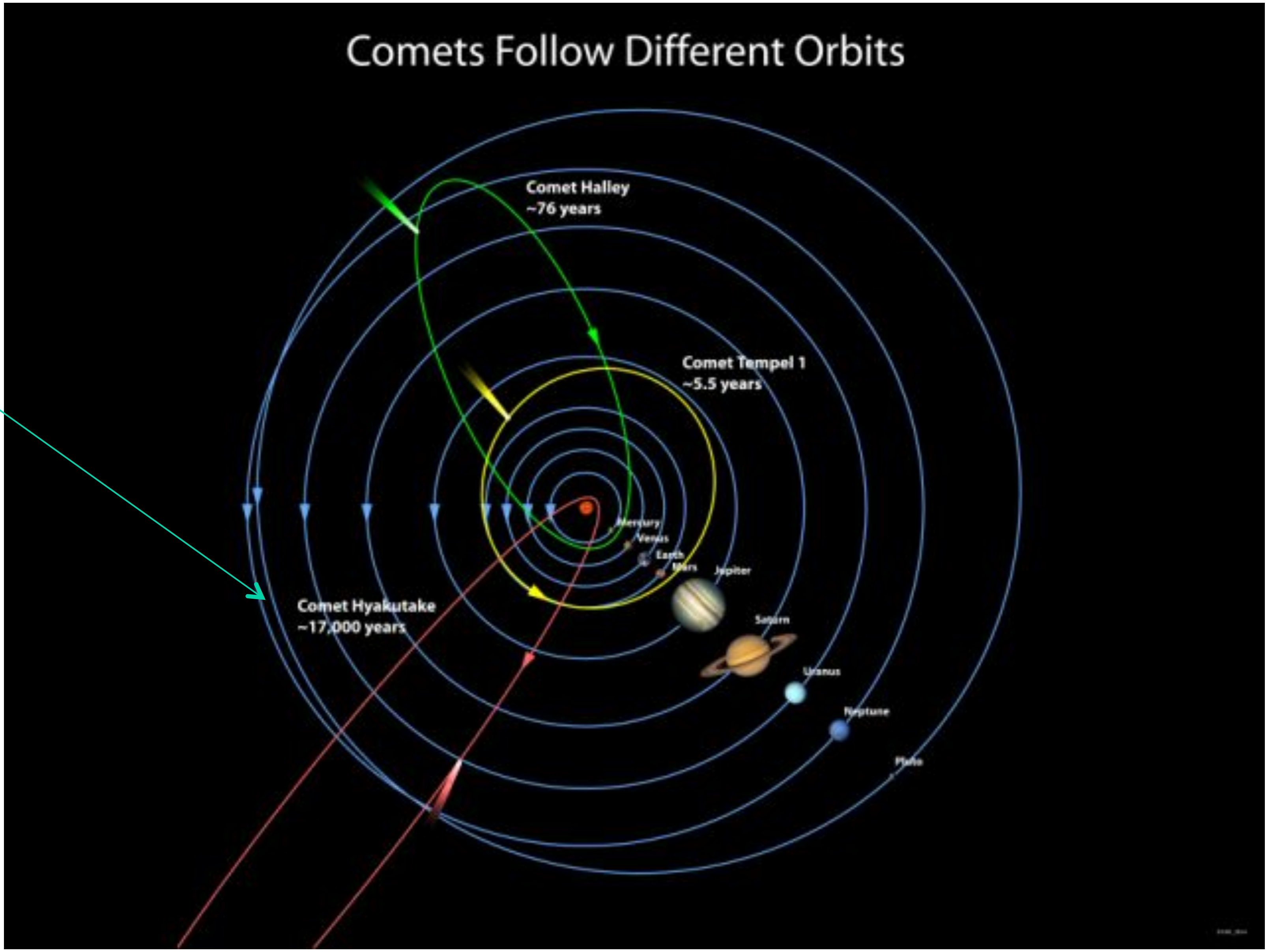
Mercury

- Closest planet to the sun
- Tugs on Mercury perturb orbit
- Not covered by Newtonian physics
- Another planet closer to the sun?
  - Vulcan, Spock's planet
- …or effects of general relativity
  - hint: it's not Vulcan



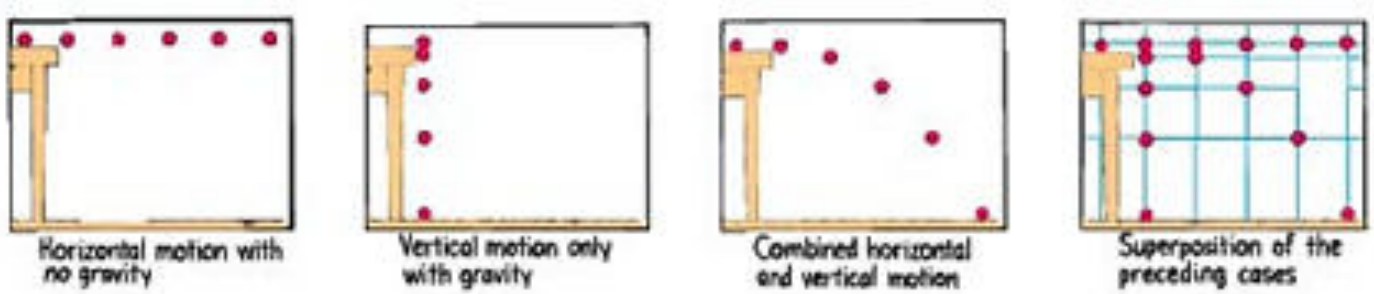
Orbits

From 1979 to 1999 Pluto was closer to the Sun than Neptune



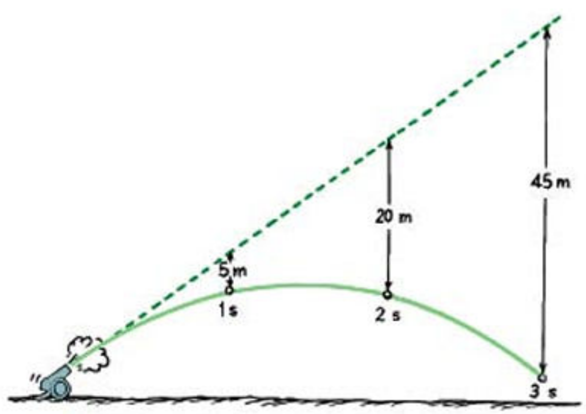
Vertical and horizontal motions

- 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

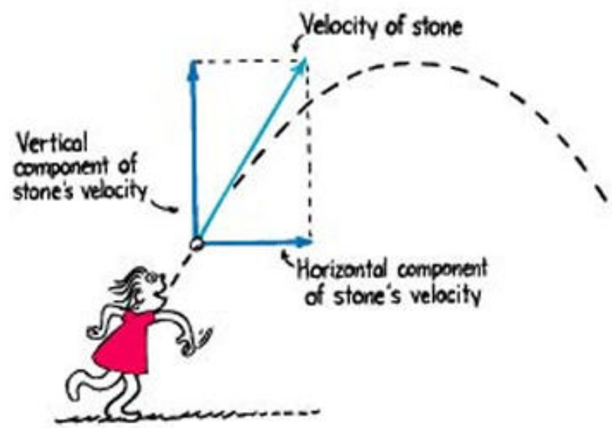


Projectile motion

- With no gravity, the cannon ball would follow a straight line
- Because of the acceleration due to gravity, it follows a parabolic path



- If I throw a stone, it will also follow a parabolic path



simulation

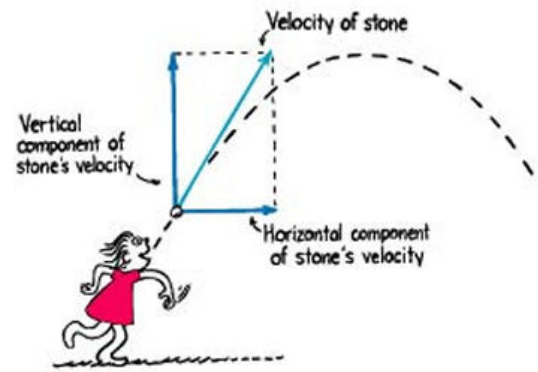
Projectile Motion

- So we have motion in both the x and y directions
- And the two motions are independent so we can write down two separate equations for the x and y motions

$$x = x_0 + v_0^x t + \frac{1}{2} a_x t^2$$

$$y = y_0 + v_0^y t + \frac{1}{2} a_y t^2$$

- I can simplify somewhat since there is no acceleration in the x direction and I can write the acceleration in the y direction as -g

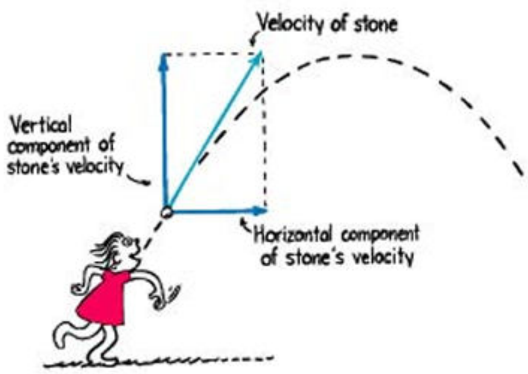


$$x = x_0 + v_0^x t$$

$$y = y_0 + v_0^y t - \frac{1}{2} g t^2$$

Projectile Motion

- Let's start simple
- I throw the ball horizontally with a speed of 20 m/s
- How long before it hits the ground?
- How far has it travelled?



$$x = x_0 + v_0^x t$$

$$y = y_0 + v_0^y t - \frac{1}{2} g t^2$$

Projectile Motion

- Assume that I release it 2 m from the ground
- y_o=2m, v_o^y=0 m/s

$$y = y_o - \frac{1}{2}gt^2$$

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

$$t^2 = \frac{4m}{9.83m/s^2} = 0.407s^2$$

$$t = 0.64s$$

$$x = x_o + 20m/s(0.64s) = x_o + 12.8m$$

$$x = x_0 + v_0^x t$$

$$y = y_0 + v_0^y t - \frac{1}{2}gt^2$$

Projectile Motion

- Suppose I throw it at 20 m/s at an angle of 45°
- Let's again start with the vertical motion
  - how long before it hits the ground?

$$0 = 2m + (20m/s)\sin 45^o t - \frac{1}{2}(9.83m/s^2)t^2$$

$$0 = 2m + (20m/s)(0.707)t - (4.915m/s^2)t^2$$

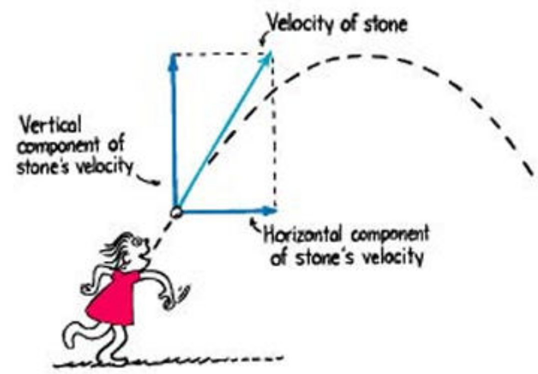
$$4.915t^2 - 14.14t - 2 = 0$$

$$t = 3.01s$$

- Now the horizontal motion

$$x = x_0 + (20m/s)\cos 45^o t$$

$$x = x_0 + (20m/s)(0.707)(3.01s) = x_0 + 42.6m$$



$$x = x_0 + v_0^x t$$

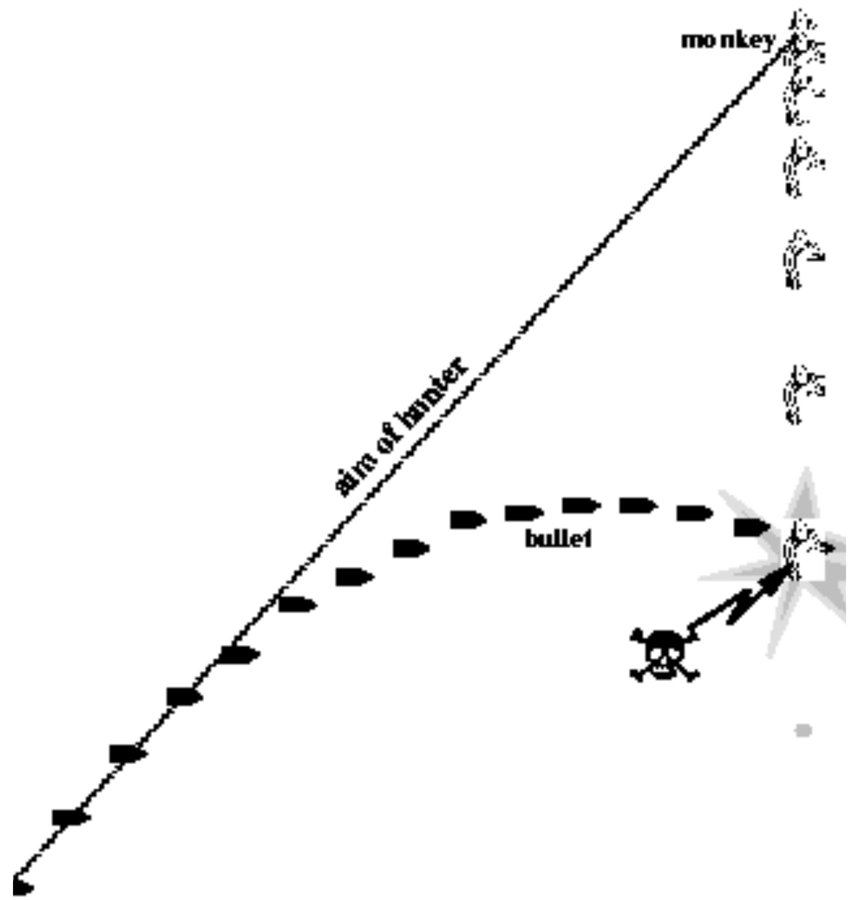
$$y = y_0 + v_0^y t - \frac{1}{2}gt^2$$

Projectile motion
Shoot the monkey

‘Shoot the monkey’

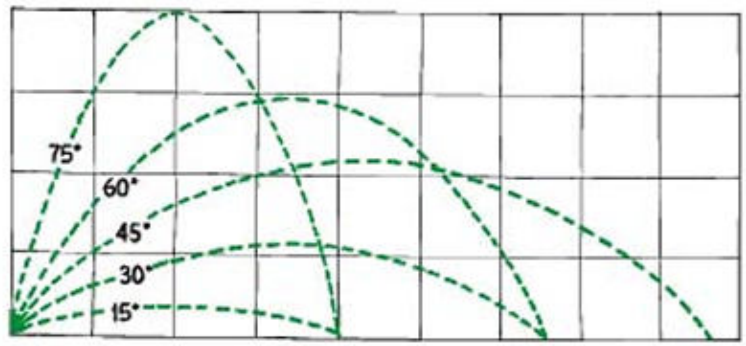
- We said that the vertical and horizontal motions for projectiles were independent
- Neglecting air resistance, there is an acceleration only in the vertical direction (due to gravity) and it is the same regardless of whether there is horizontal motion or not
- Suppose a hunter is aiming at a monkey 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

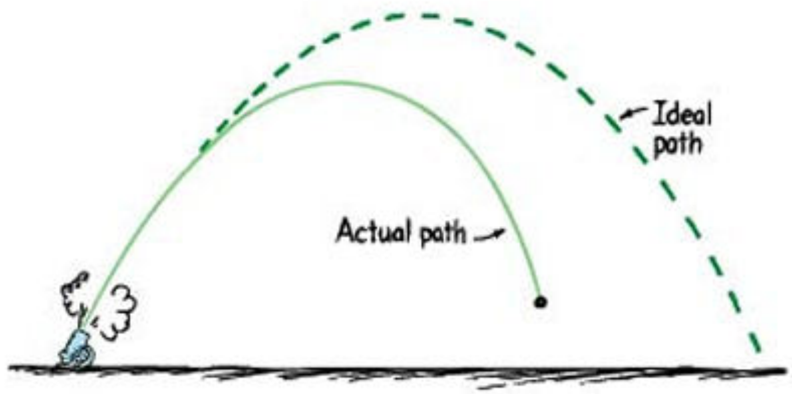
Figure 4.5: Shoot the ``monkey'': an illustration o
motion in two dimensions.



…no actual monkeys will be harmed in this demonstration

- What angle should you throw a ball in order for it to go the maximum distance, given that the initial release velocity is the same?
  - somewhere between 0 and 90 degrees
  - to be more precise 45 degrees
- What is the impact of air resistance?

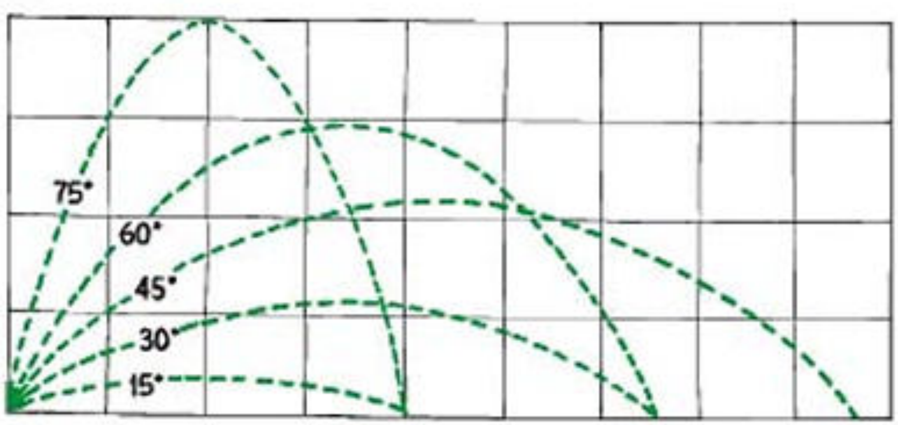




Clicker question

- For the possible paths for the projectile below, which has the largest vertical acceleration?

- A) 75°
- B) 60°
- C) 45°
- D) 30°
- E) they're all the same



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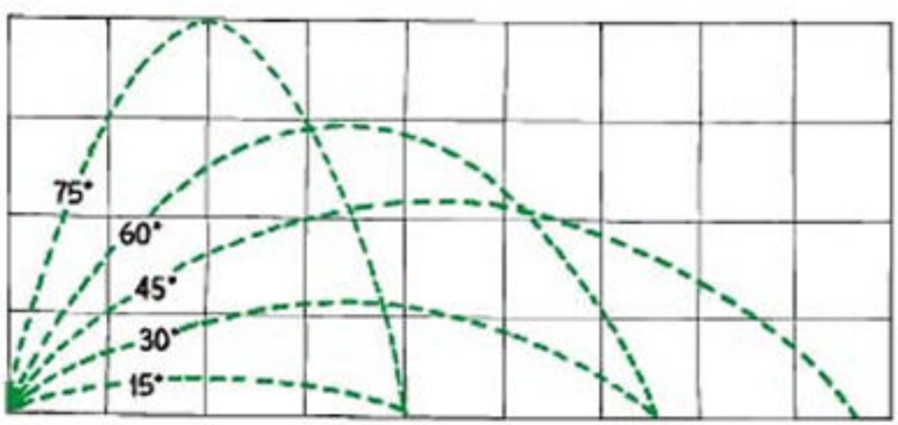
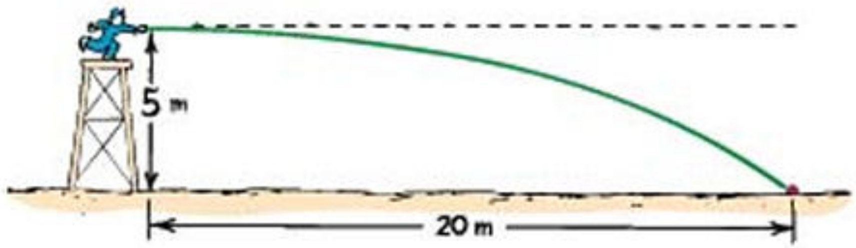
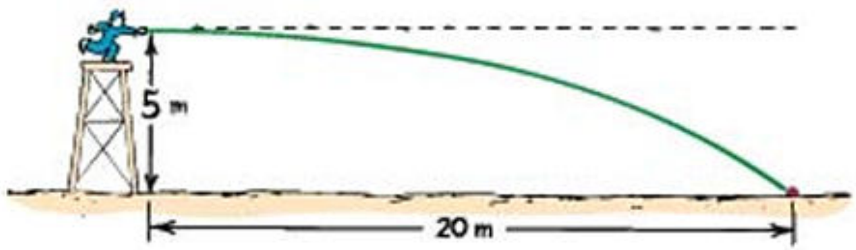


- How fast is the ball thrown?
- How would you approach the problem?



- 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?
- How would you approac the problem?
- Separate into horizontal and vertical motions
- **How long does it take for the ball to drop 5 m?**
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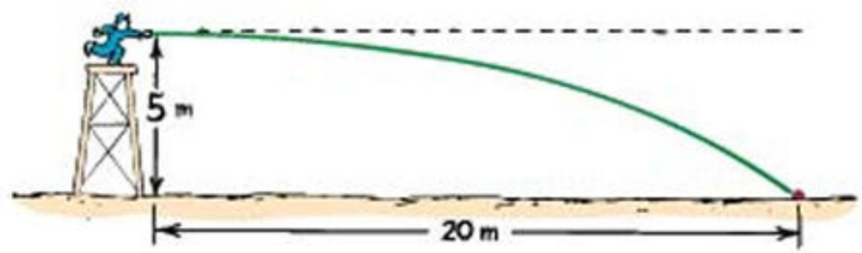


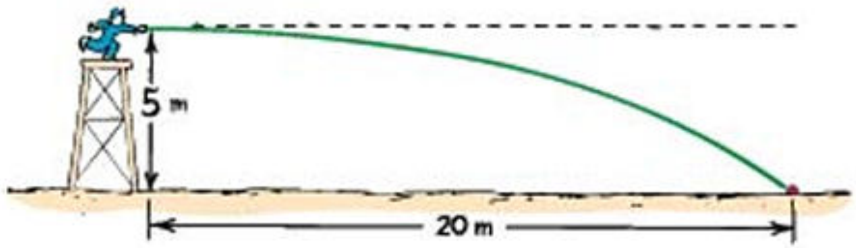
$$y = y_o + v_o^y t - \frac{1}{2} g t^2$$

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

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

$$t = 1.01s$$

- **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



$$t = 1.01s$$

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

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

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

iclicker question

A cannonball is fired horizontally with a speed of 10 m/s from the edge of a cliff. What is its speed 1 second after being fired? Ignore air resistance.

a) 10 m/s
b) 14 m/s
c) 16 m/s
d) 20 m/s
e) 30 m/s

iclicker question

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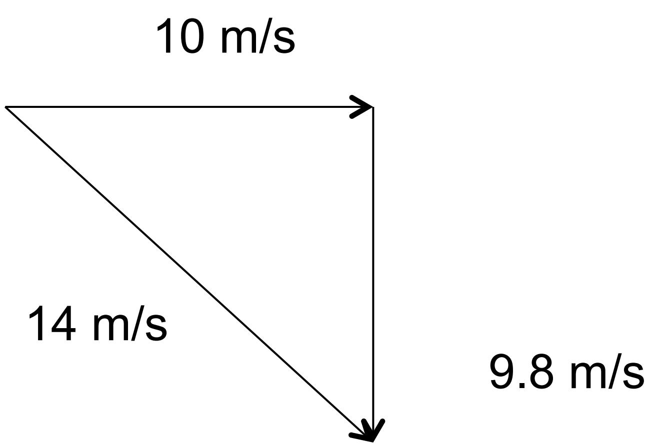

Satellites

- 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