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## Today

- Announcements:
  - HW#3 is due by 8:00 am Wednesday January 30th.
  - A second extra credit problem will be available next week
- Gravity
- Force
- Vectors



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## History of astronomy

- Ptolomy devised an Earth-centered model of the motion of planets that worked well
- Brahe made detailed measurements that showed deficiencies in the model
- Kepler discarded the previous assumptions and devised his three laws of planetary motion with the Sun at the center
- Newton unified the tree laws with his Universal Law of Gravity



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## Planetary Orbits

- We will use the program Interactive Physics to demonstrate planetary orbits.
- Newton recognized the acceleration of the Moon and knew that a force from the Earth must be responsible. He called this gravity.
- At the time it was questioned because people would not accept force at a distance.
- But, what does cause gravity? More later …



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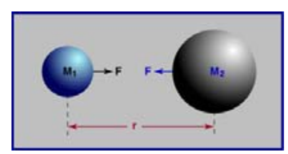
## Newton’s Universal Law of Gravity

Newton’s Universal Law of Gravity:

$$F = \frac{Gm_1m_2}{r^2}; G = 6.673E-11 \, {}^{Nm^2}\!/_{kg^2}$$



WHY?

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## The Law of Gravity

What is the force of gravity on a 90 kg professor standing on the surface of the Earth?

$$F = \frac{G m_p m_e}{r_e^2} = \frac{\left(6.673E-11 \, Nm^2/kg^2\right) 90kg \times 5.974E24\,kg}{\left(6.378E6\,m\right)^2} = 882\ N$$

*Note: We get the same answer if we ask what is the force a professor exerts on the Earth. That is Newton's third law.*



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## Two examples using the Law of Gravity

- What is the acceleration caused by this force? $F = ma \rightarrow a \equiv g = \frac{F}{m} = \frac{882N}{90kg} = 9.795\, m/s^2$
- What would happen if the radius of the Earth were doubled, but the mass was the same? $F_{2r} = \frac{G m_e m_p}{\left(2r_e\right)^2} = \frac{G m_e m_p}{4\left(r_e\right)^2} = \frac{1}{4} \times F_r$



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## Force of gravity on an astronaut

What is the force if the 90 kg professor is in the space shuttle at 300 km above the Earth?

$$300km = 300km \times \frac{1000m}{km} = 3.00E5\,m$$

$$F = \frac{G m_e m_p}{r_e^2} = \frac{\left(6.673E-11 \, Nm^2/kg^2\right) 90kg \times 5.974E24\,kg}{\left(\underbrace{6.378E6\,m}_{r_e} + \underbrace{3.00E5\,m}_{r_{orbit}}\right)^2} = 804\ N$$

$r_e$ + $r_{orbit}$



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## More on Gravity

On the surface of the Earth:

$$F = \frac{G m_e m}{r_e^2} = \left(\frac{G m_e}{r_e^2}\right) m = ma = mg$$

$$G = 6.673E-11\, Nm^2/kg^2$$

$$g = 9.81\, m/s^2 \text{ (g - symbol for the acceleration of gravity)}$$

## All objects fall at the same rate

- $F_{Gravity}$ = mg (the mass and radius of Earth are in the g)
- Also F = ma = mg (Note: this is a vector equation, whatever direction F points, a points that way too!)
- Therefore, neglecting other forces

$$\boxed{g = a}$$

- More mass means more F, but more mass also means it is harder to accelerate. These two effects cancel.
- Why is the m in ma the same as the m in mg?



## Newton Explains Kepler's Laws

- Elliptical orbits

$$F = \frac{Gm_1m_2}{r^2}; G = 6.673E-11 \, {}^{Nm^2}\!/_{kg^2}$$

- The stronger force means more acceleration when the planet is closer to the star
- A larger distance means less force and a longer time for the orbit
- Newton's law of gravity unified three laws in one.



## Newtonian View of the Universe

• Loss of free will

• French Scientist/Mathematician Pierre-Simon Laplace (1749-1827)

"An intelligence which at a given instant knew all the forces acting in nature and the positions of every object in the universe - if endowed with a brain sufficiently vast to make all the necessary calculations – could describe with a single formula the motions of the largest astronomical bodies and those of the lightest atoms. To such an intelligence, nothing would be uncertain; the future, like the past, would be an open book."



## Nature was thought to be understood

From 1894:
"The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote.... Our future discoveries must be looked for in the sixth place of decimals." - Albert. A. Michelson, speech at the dedication of Ryerson Physics Lab, U. of Chicago 1894

From 1900:
"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement" - Lord Kelvin

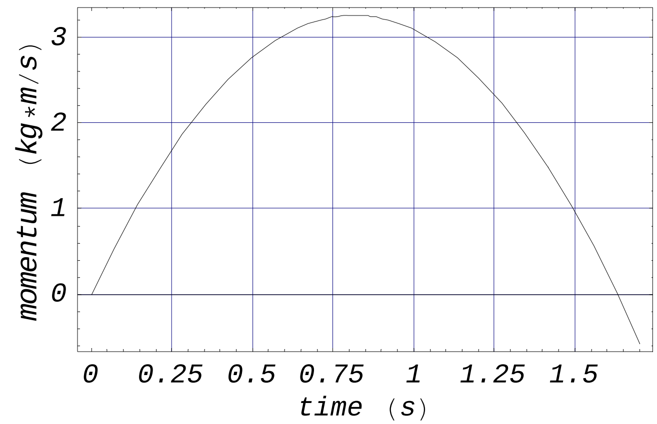
## A more modern view of force

- Force is the rate of change of momentum.
- Momentum is mass times velocity.
- Momentum is a vector. Often we write it as a "p" .
- p=mass · velocity
- Momentum is the modern analog to Galileo's idea of inertia.





## Momentum Problem Picture








## Momentum Problems

Hint: Force is the rate of change of momentum.

$$\vec{F} = \frac{\Delta \vec{p}}{\Delta t} = \frac{\vec{p}_2 - \vec{p}_1}{t_2 - t_1}$$

$$\text{magnitude of F for motion in one dimension} = \frac{p_2 - p_1}{t_2 - t_1}$$

Note: A negative slope means the direction of the force is toward –x. Force is a vector, and direction matters.

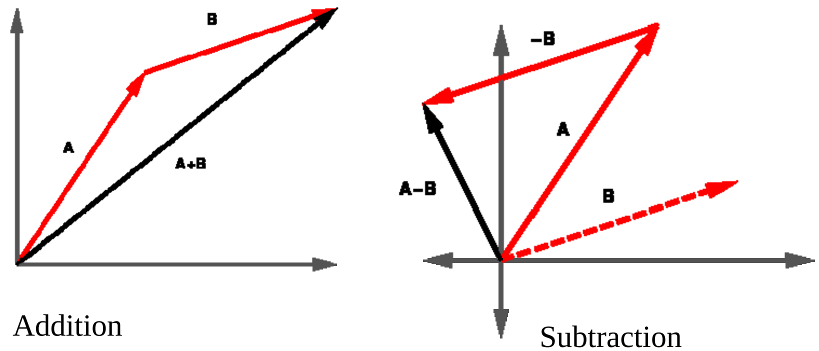




## What is a force (continued)?

- These laws let us recognize a force, but what causes a force?
  - The modern view is related to field theory.
  - Forces are the result of an exchange of particles.
- To understand field theory, we have to talk about energy and quantum mechanics (later in the term).

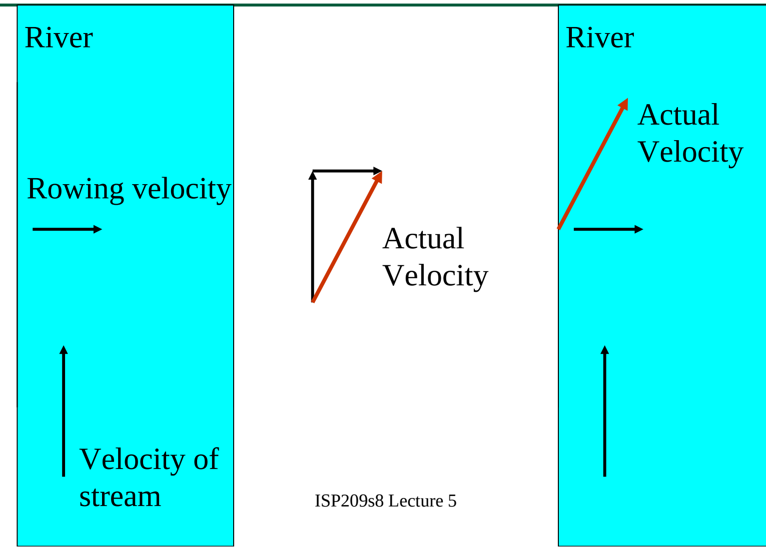
# Vector Addition and Subtraction







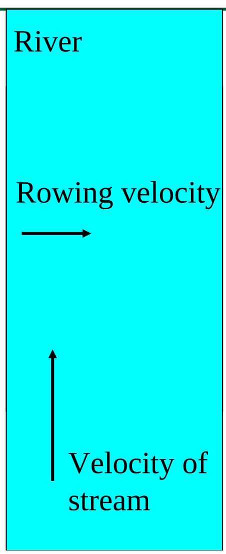

# Example of the use of vectors








# How long to cross the river?




$$\text{time} = \frac{\text{distance across the river}}{\text{rowing speed}}$$

The rowing speed is the magnitude of the boat's velocity directed toward the opposite bank.





# Vectors