Physics 121.
Tuesday, March 4, 2008.

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- Course Information
- Quiz
- Topics to be discussed today:
  - Conservation of linear momentum (a brief review)
  - One- and two-dimensional collisions (elastic and inelastic)

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- Homework set # 5 is now available on the WEB and will be due next week on Saturday morning, March 8, at 8.30 am.

- To download the collision videos:
  - OSX: use control-click while pointing to the movie links to download the linked file.
  - Windows: use right-click while pointing to the movie links to download the linked file.

- The most effective way to work on the assignment is to tackle 1 - 2 problems a day.

- Note: clicking on the "Email instructor" button sends an email to the instructor and the TAs.

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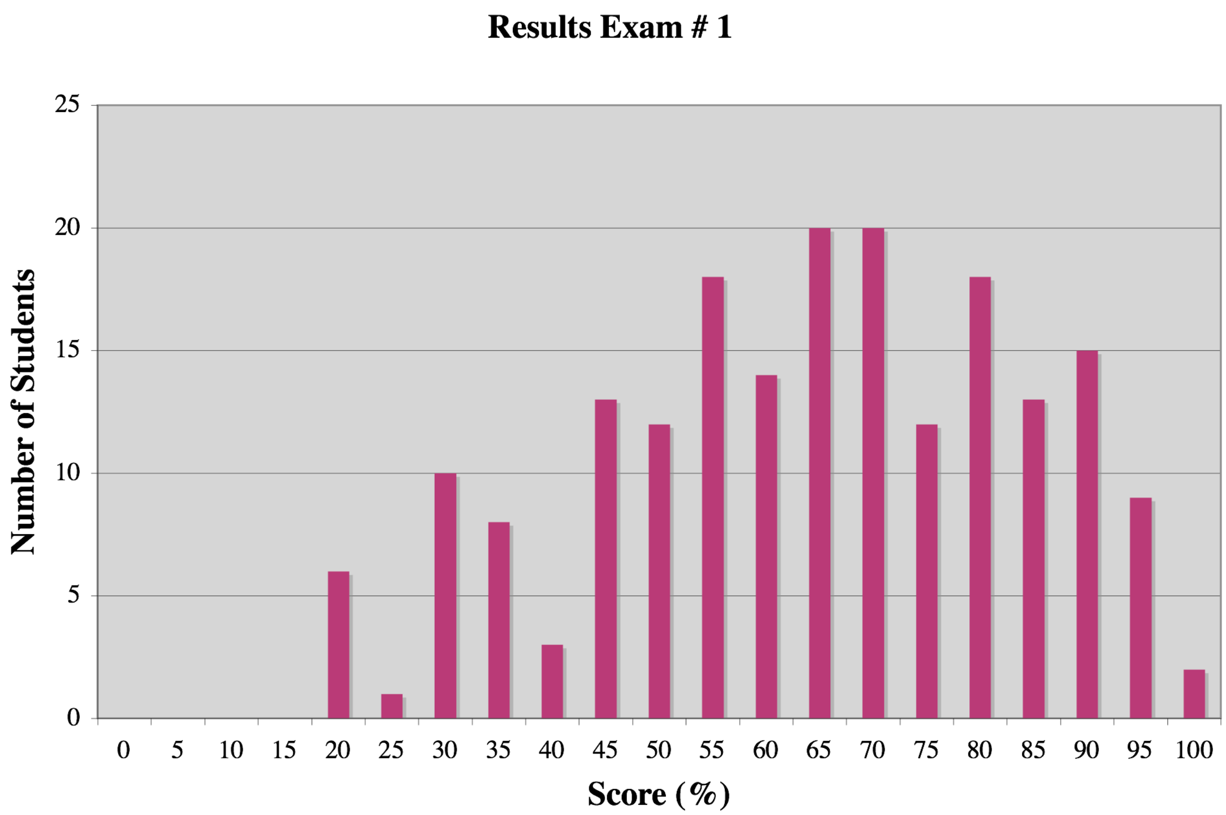
- Exam # 1 will be returned to you during the workshops this week.

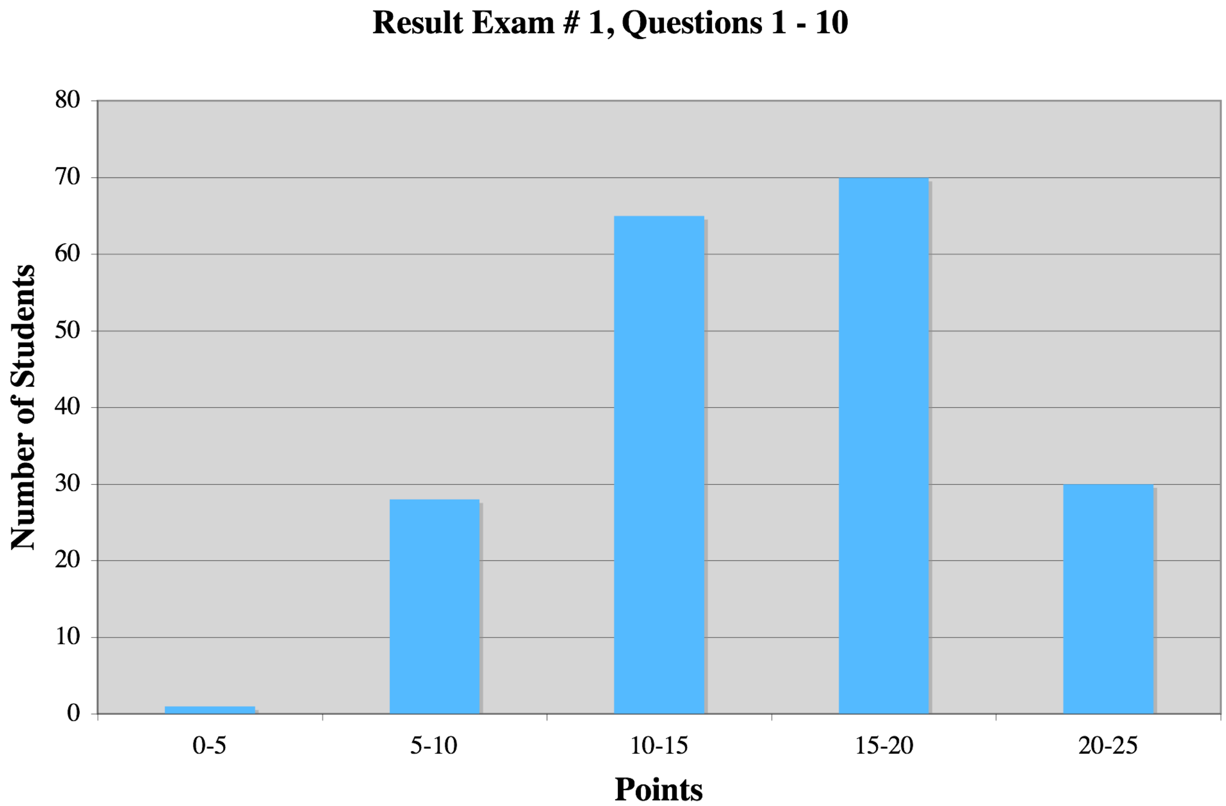
- Any corrections to the grading of the exams can only be made by me.

- My office hours this week have been moved from Tuesday between 11.30 am and 1.30 pm to Thursday between 11.30 am and 1.30 pm.

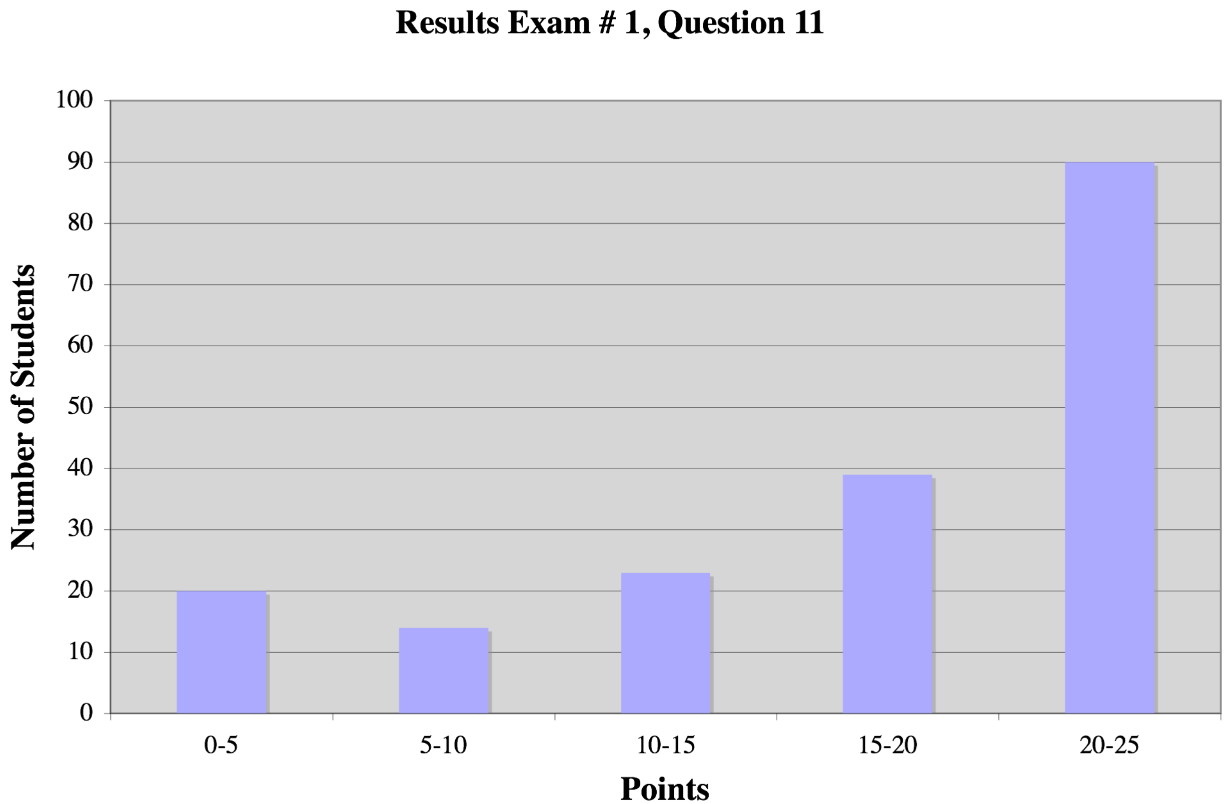
Results Midterm Exam # 1.



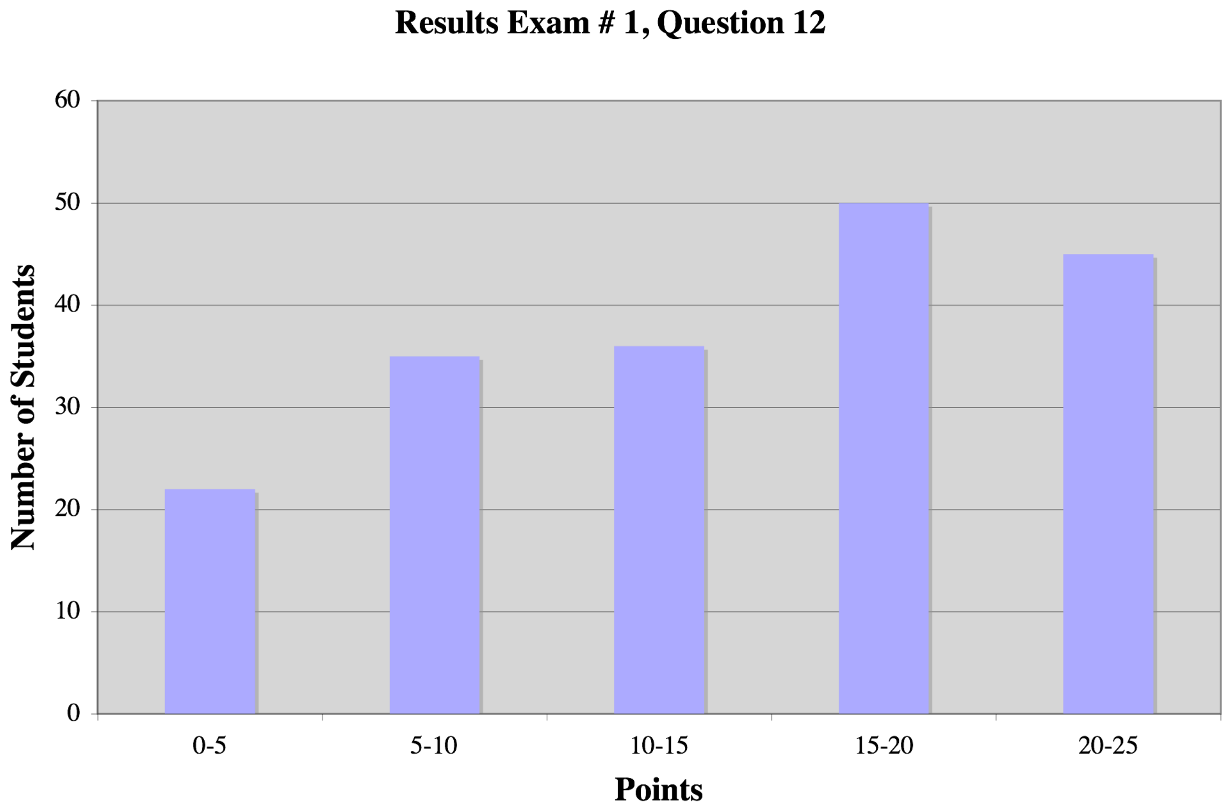
Question 1 - 10, Exam # 1.
Only 8 students struggled with Q 10.



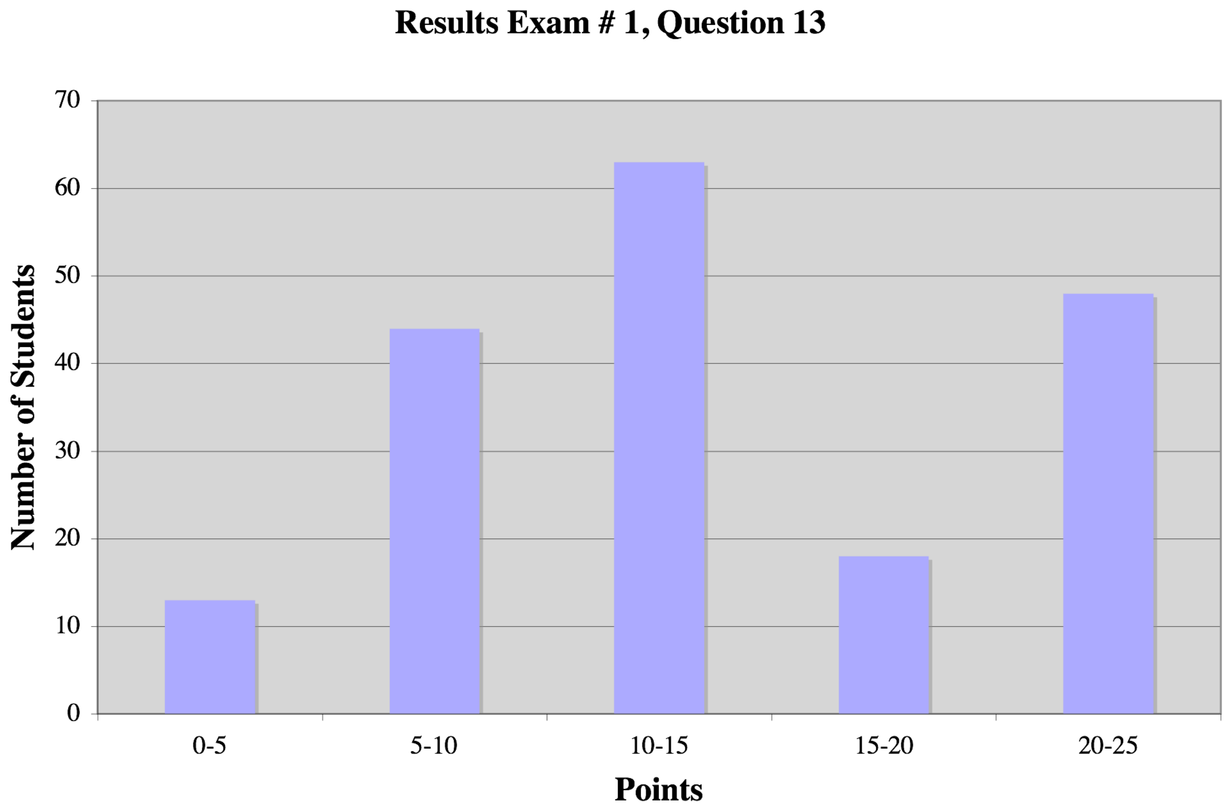
Question 11, Exam # 1.



Question 12, Exam # 1.



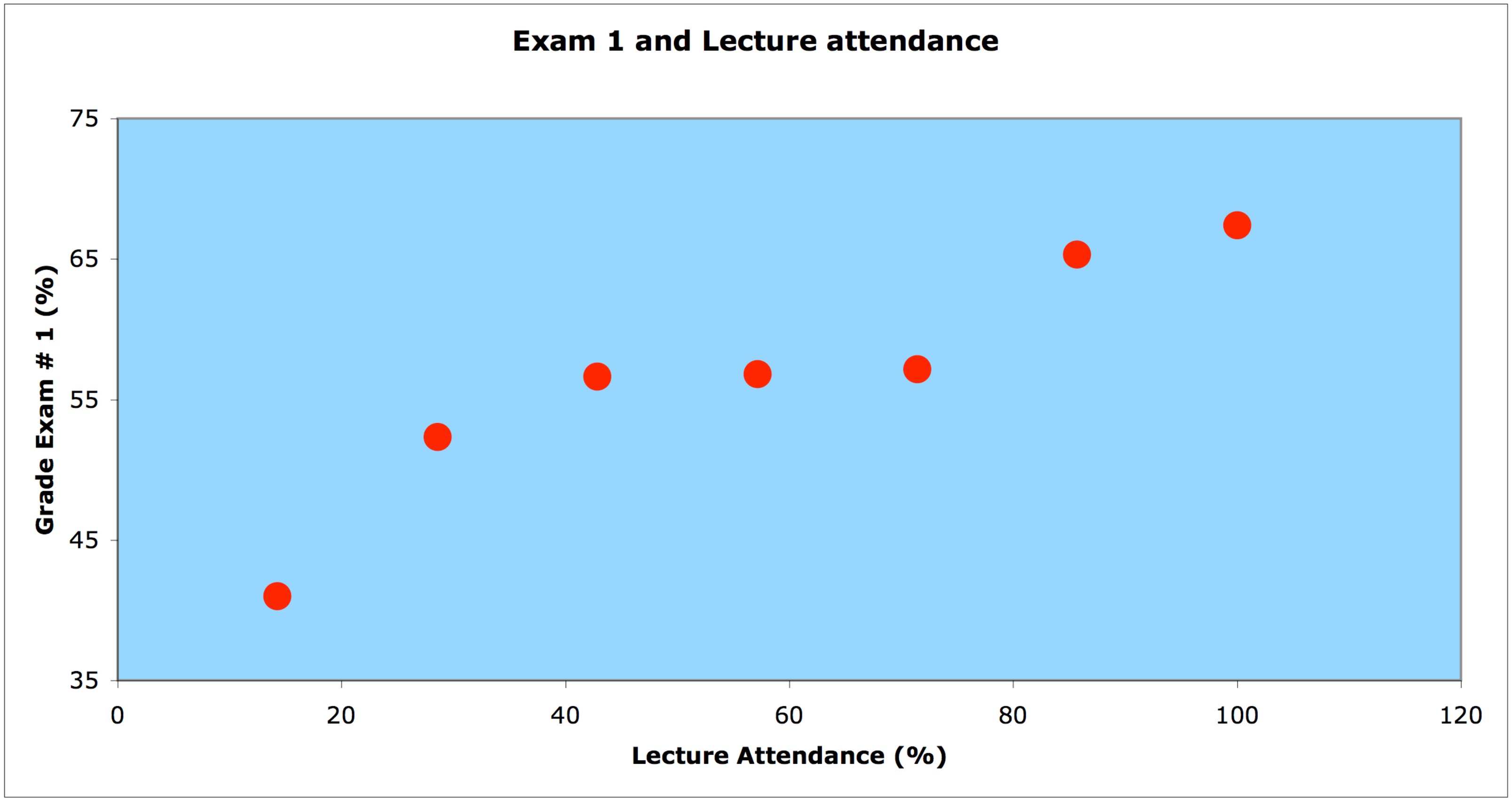
Question 13, Exam # 1.



Results Midterm Exam # 1.

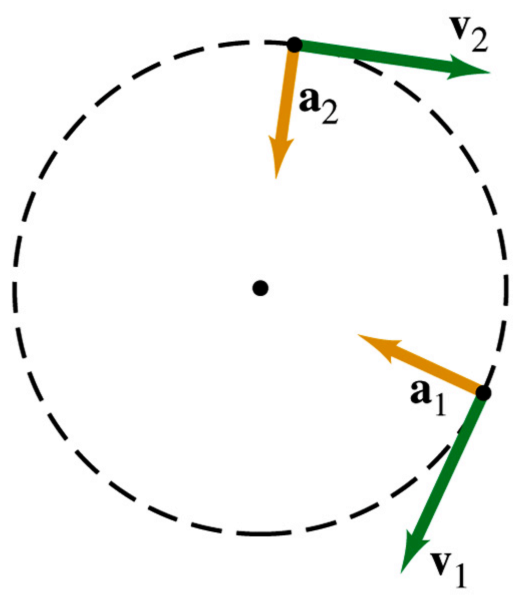
- Observations:
  - Circular motion causes many problems.
  - Some students had difficulty getting started - what approach to take.
  - Many students had difficulty with clearly expressing their thought process (we can only award partial credit, if we can follow what you are doing).
- Recommendations:
  - If your score is below 50% you really need to ask why?
    - Are you giving this course enough time?
    - Do you come to lecture (and stay after the quiz)?
    - Do you go to workshops?
    - Do you work on the homework assignments in an efficient manner (not waiting until the last moment to start working on it)?
    - Do you look at the homework solutions?
    - Did you look at the practice exam?
    - Did you feel prepared? If not, why not? If not, did you ask for help?

Attending class (after the quiz) actually makes a difference.



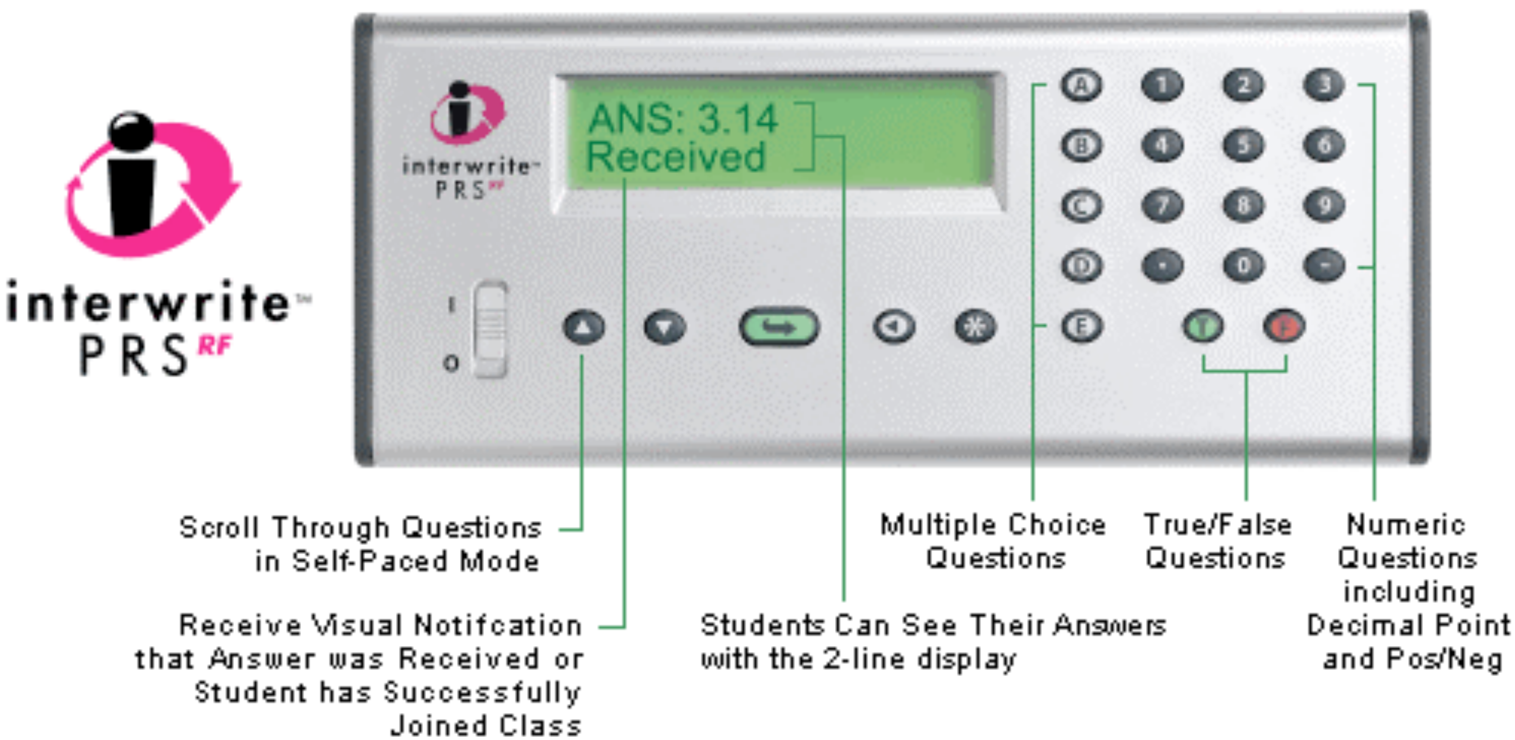
Results Midterm Exam # 1

- Some comments on circular motion:
  - Anytime you observe circular motion, you know that the net force must be directed towards the center of the circle with a magnitude of mv^2/r.
  - This force can be provided in different ways. For example:
    - Tension
    - Gravitational force
    - Normal force



Physics 121.
Quiz lecture 13.

- The quiz today will have 4 questions!



The center of mass (a review).

- The position of the center of mass of a system of particles along the x-axis is defined as

$$x_{cm} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2} = \frac{1}{M} \sum_i m_i x_i$$

and similar expressions for the y and z positions.

- The motion of the center of mass is determined by the externals forces acting on the system:

$$M\vec{a}_{cm} = \sum_i m_i \vec{a}_i = \sum_i \vec{F}_i = \vec{F}_{net,ext}$$

Linear momentum (a review).

- The product of the mass and velocity of an object is called the linear momentum p of that object.
- In the case of an extended object, we find the total linear momentum by adding the linear momenta of all of its components:

$$\vec{P}_{tot} = \sum_i \vec{p}_i = \sum_i m_i \vec{v}_i = M\vec{v}_{cm}$$

- The change in the linear momentum of the system can now be calculated:

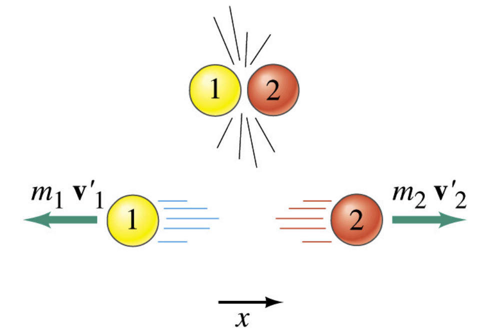
$$\frac{d\vec{P}_{cm}}{dt} = \frac{d}{dt}\left(M\vec{v}_{cm}\right) = M\frac{d\vec{v}_{cm}}{dt} = M\vec{a}_{cm} = \sum_i m_i \vec{a}_i = \sum_i \vec{F}_i = \vec{F}_{net,ext}$$

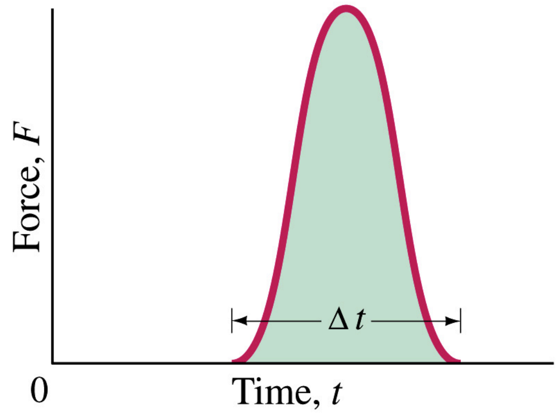
- This relations shows us that if there are no external forces, the total linear momentum of the system will be constant (independent of time).

Collisions.
The collision force.

- During a collision, a strong force is exerted on the colliding objects for a short period of time.
- The collision force is usually much stronger then any external force.
- The result of the collision force is a change in the linear momentum of the colliding objects.
- The change in the momentum of one of the objects is equal to

$$\vec{p}_f - \vec{p}_i = \int_{\vec{p}_i}^{\vec{p}_f} d\vec{p} = \int_{t_i}^{t_f} \vec{F}(t)\, dt$$





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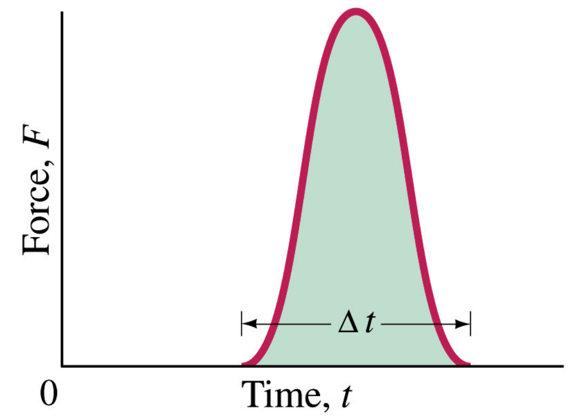
Collisions.
The collision impulse.

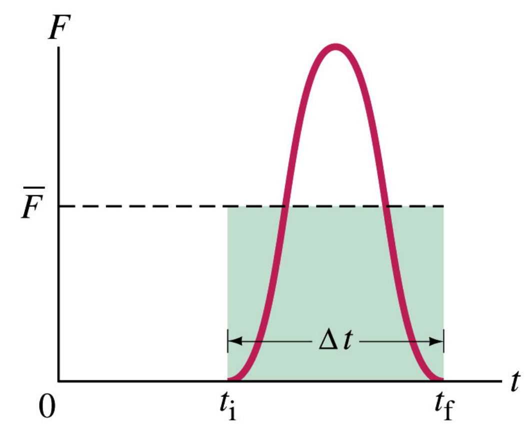
- If we measure the change in the linear momentum of an object we will obtain information about the integral of the force acting on it:

$$\vec{p}_f - \vec{p}_i = \int_{\vec{p}_i}^{\vec{p}_f} d\vec{p} = \int_{t_i}^{t_f} \vec{F}(t)\,dt$$

- The integral of the force is called the collision impulse *J*:

$$\vec{J}_i = \int_{\vec{p}_i}^{\vec{p}_f} d\vec{p} = \int_{t_i}^{t_f} \vec{F}(t)\,dt$$



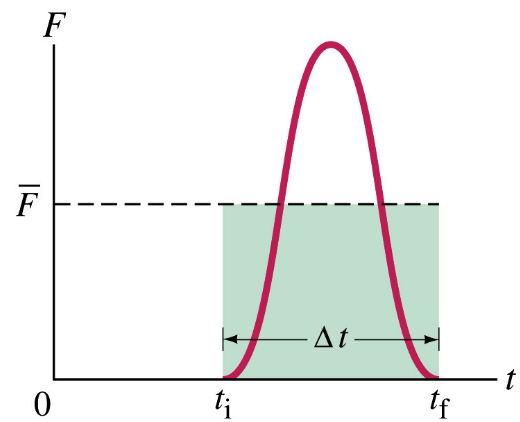


Collisions.
The collision impulse.

- Consider you are involved in a collision: you first move with 55 mph and after the collision you are at rest.
- The change in momentum is thus fixed and the collision impulse is also fixed:

$$\vec{J}_i = \int_{t_i}^{t_f} \vec{F}(t)\, dt$$

- What happens to you depends on the magnitude of the force! An increase in time Δt results in a reduction of the force.



Collisions.
The collision impulse.

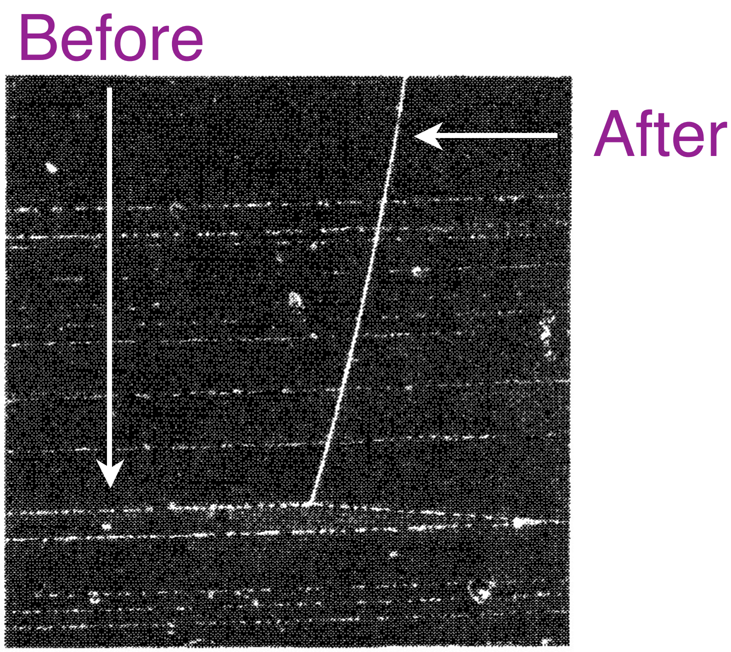
- Increasing the time required to come to a stop reduced the average force.
- This reduction in the average force can mean the difference between life and death.
- The human body can tolerate accelerations up to 10 - 15 times the gravitational acceleration.
- An acceleration of $10g$ brings an object traveling at 55 mph to rest over a distance of 3 m (9 feet).

Collisions.
The collision impulse.

- Interactions between sub-atomic particles are usually studied by comparing their momenta before and after an interaction.

- The change in their momenta provides us with information about the collision impulse.

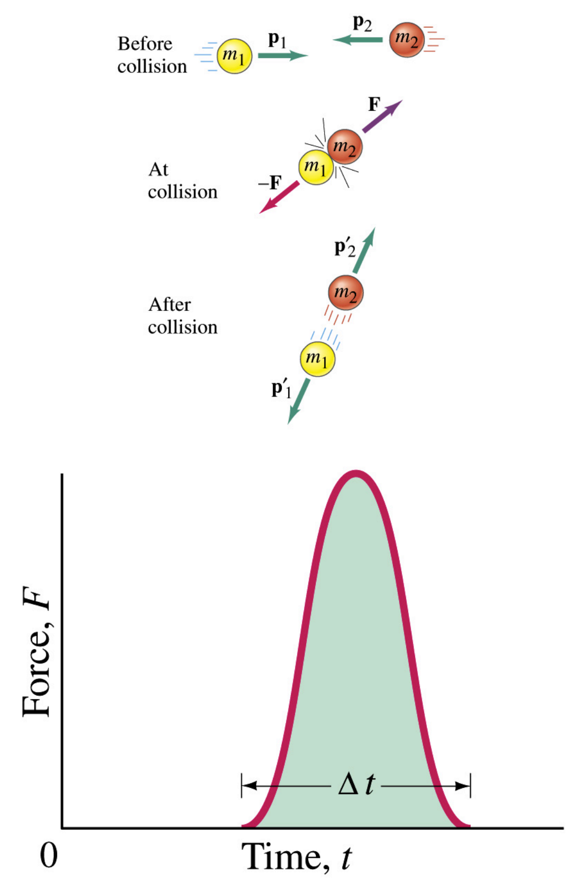
- Determining the force from the collision impulse required a knowledge of the time dependence of the interaction.



Collision between protons.

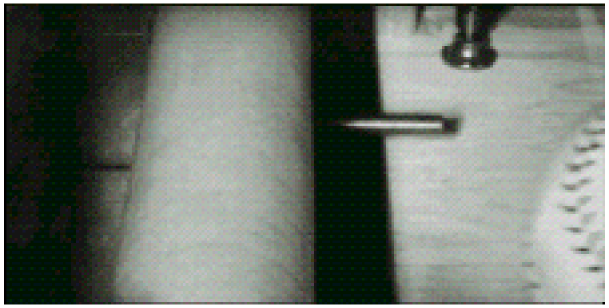
Elastic and inelastic collisions.

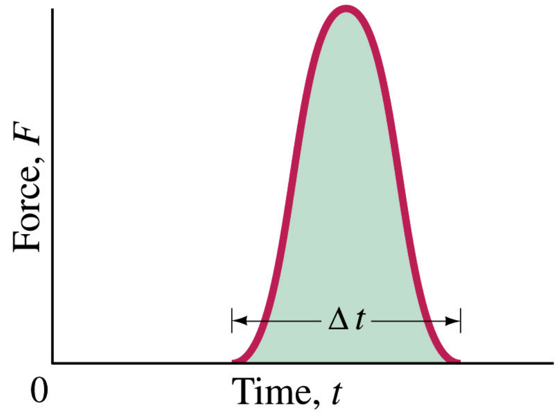
- If we consider both colliding object, then the collision force becomes an internal force and the total linear momentum of the system must be conserved if there are no external forces acting on the system.
- Collisions are usually divided into two groups:
  - Elastic collisions: **kinetic energy is conserved**.
  - Inelastic collisions: **kinetic energy is NOT conserved**.



Elastic and inelastic collisions.

- Kinetic energy does not need to be conserved during the time period that the collision force is acting on the system. The kinetic energy may become 0 J for a short period of time.
- During the time period that the collision force is non-zero, some or all of the initial kinetic energy may be converted into potential energy (for example, the potential energy associated with deformation).





Elastic collisions in one dimension.

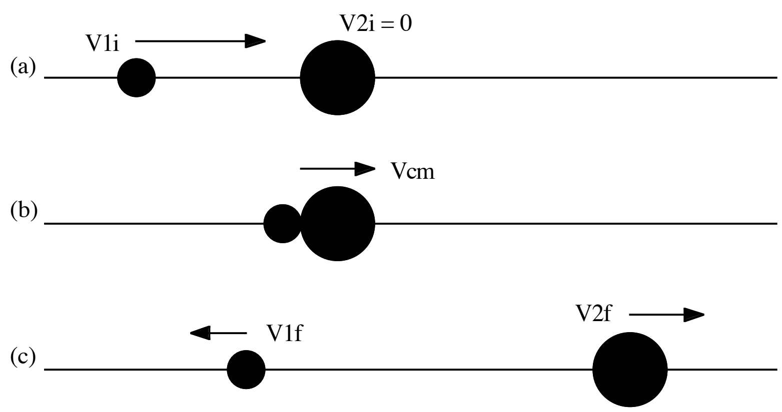
- Consider the elastic collision show in the Figure.
- Conservation of linear momentum requires that

$$m_1 v_{1i} = m_1 v_{1f} + m_2 v_{2f}$$

- Conservation of kinetic energy requires that

$$\frac{1}{2} m_1 v_{1i}^{\ 2} = \frac{1}{2} m_1 v_{1f}^{\ 2} + \frac{1}{2} m_2 v_{2f}^{\ 2}$$

- Two equations with two unknown!



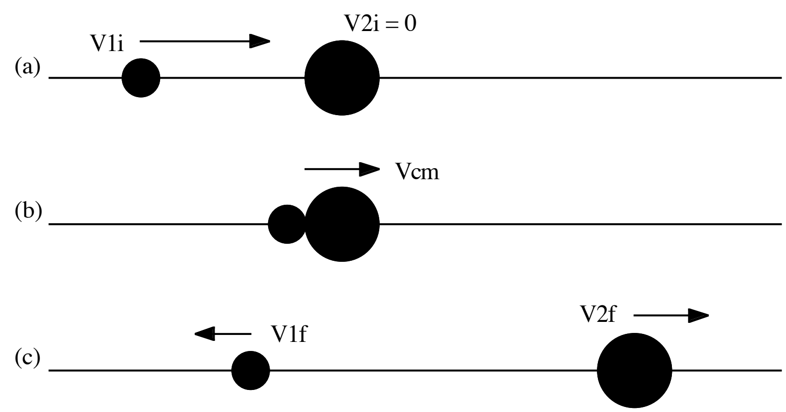
Elastic collisions in one dimension.

- The solution for the final velocity of mass m_1 is:

$$v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i}$$

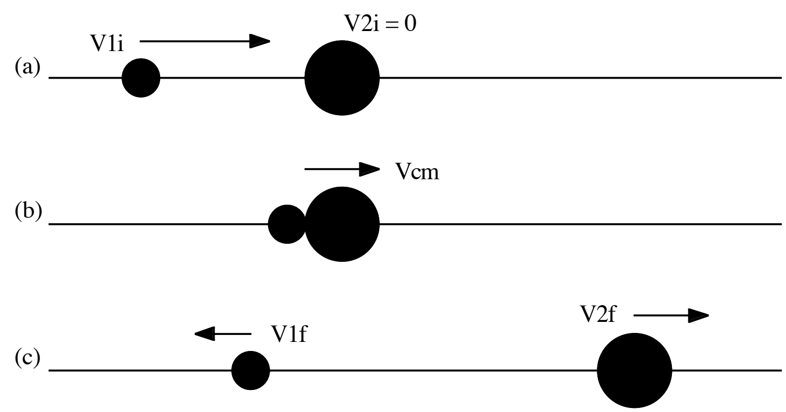
- The solution for the final velocity of mass m_2 is:

$$v_{2f} = \frac{m_1}{m_2}\left(v_{1i} - v_{1f}\right) = \frac{2m_1}{m_1 + m_2} v_{1i}$$



Elastic collisions in one dimension. Special cases.

- $m_1 = m_2$:
  - $v_{1f} = 0$ m/s
  - $v_{2f} = v_{1i}$
- $m_2 >> m_1$:
  - $v_{1f} = - v_{1i}$
  - $v_{2f} = (2m_1/m_2)\ v_{1i}$
- $m_1 >> m_2$:
  - $v_{1f} = v_{1i}$
  - $v_{2f} = 2v_{1i}$



Note: the motion of the center of mass is not changed due to the collision.

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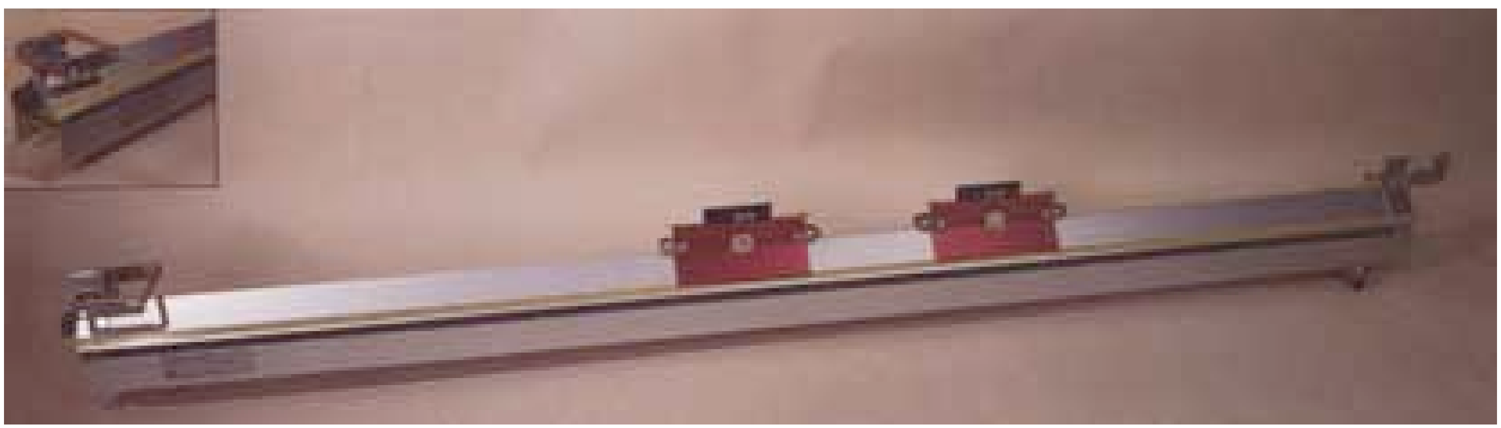
Elastic collisions in one dimension.

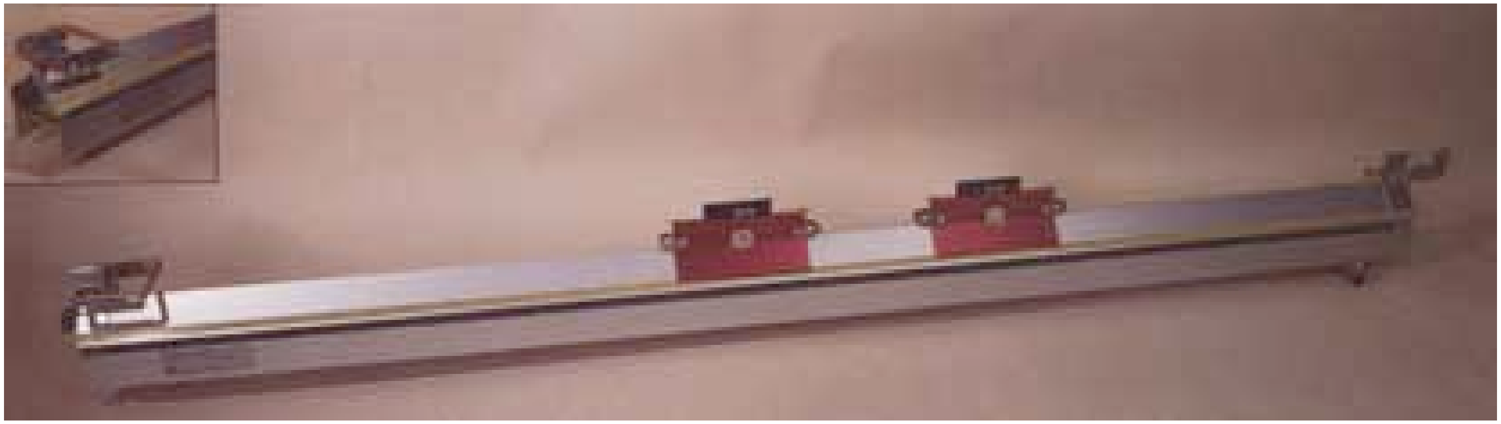
- We can use an air track to study elastic collisions.
- The velocity of the carts can be determined if we measure the length of time required to pass through the photo gates: velocity = length/time.



TEL-Atomic, http://www.telatomic.com/at.html

Elastic collisions in one dimension.

- Let us focus on specific examples where one cart (cart 2) is at rest:
  - $M_1 = M_2$: $v_{1f} = 0$ m/s, $v_{2f} = v_{1i}$
  - $M_1 = 2M_2$: $v_{1f} = (1/3)v_{1i}$, $v_{2f} = (4/3)\ v_{1i}$
  - $2M_1 = M_2$: $v_{1f} = -(1/3)v_{1i}$, $v_{2f} = (2/3)\ v_{1i}$



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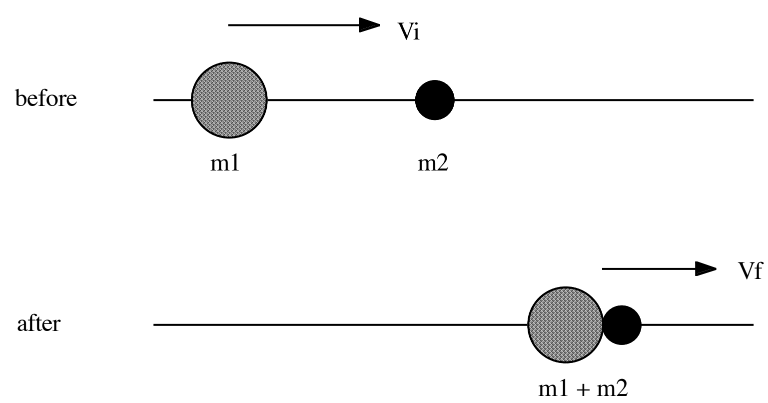
Inelastic collisions in one dimension.

- In inelastic collisions, kinetic energy is not conserved.
- A special type of inelastic collisions are the completely inelastic collisions, where the two objects stick together after the collision.
- Conservation of linear momentum in a completely inelastic collision requires that

$$m_1 v_i = (m_1 + m_2) v_f$$



Inelastic collisions in one dimension.

- The final velocity of the system is equal to

$$v_f = \frac{m_1}{m_1 + m_2} v_i$$

- The final kinetic energy of the system is equal to

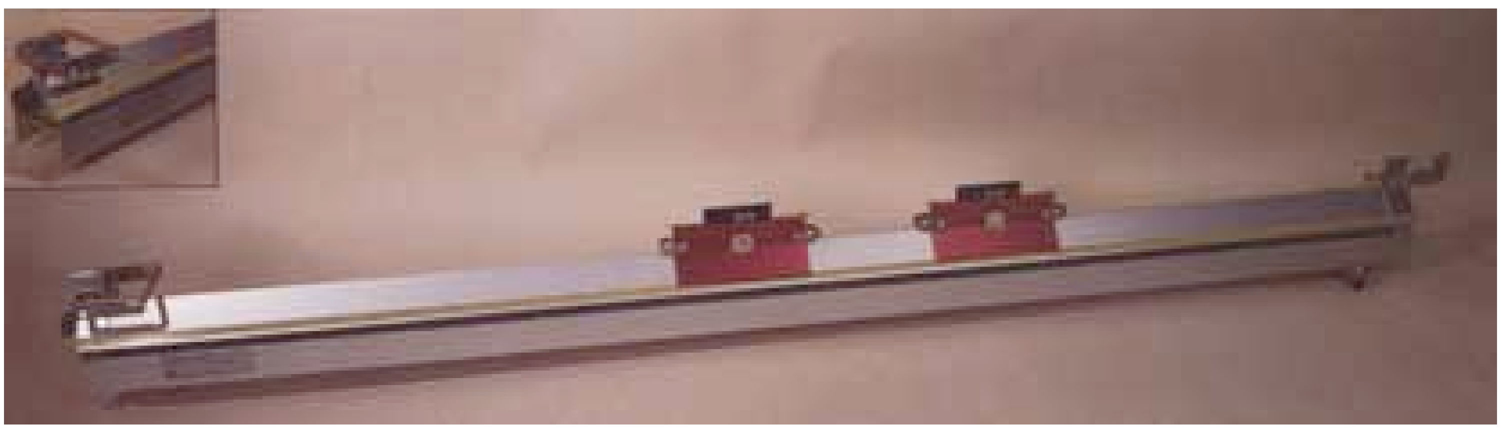
$$K_f = \frac{1}{2}\left(m_1 + m_2\right) v_f^{\,2} = \frac{1}{2}\left(m_1 + m_2\right)\left(\frac{m_1}{m_1 + m_2} v_i\right)^2 = \frac{m_1}{m_1 + m_2} K_i$$

- Note: not all the kinetic energy can be lost, even in a completely inelastic collision, since the motion of the center of mass must still be present. Only if our reference frame is chosen such that the center-of-mass velocity is zero, will the final kinetic energy in a completely inelastic collision be zero.

Inelastic collisions in one dimension.

- Let us focus on one specific example of a procedure to measure the velocity of a bullet:
  - We shoot a 0.3 g bullet into a cart.
  - The final velocity of the cart is measured and conservation of linear momentum can be used to determine the velocity of the bullet:

$$v_i = (M_1 + M_2)v_f/M_1$$



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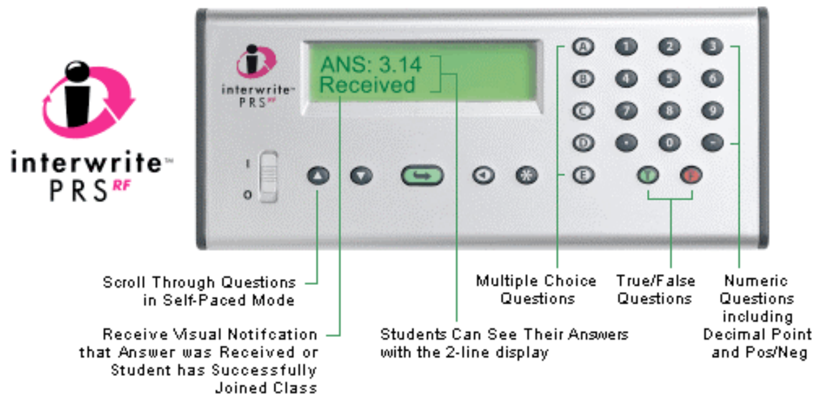
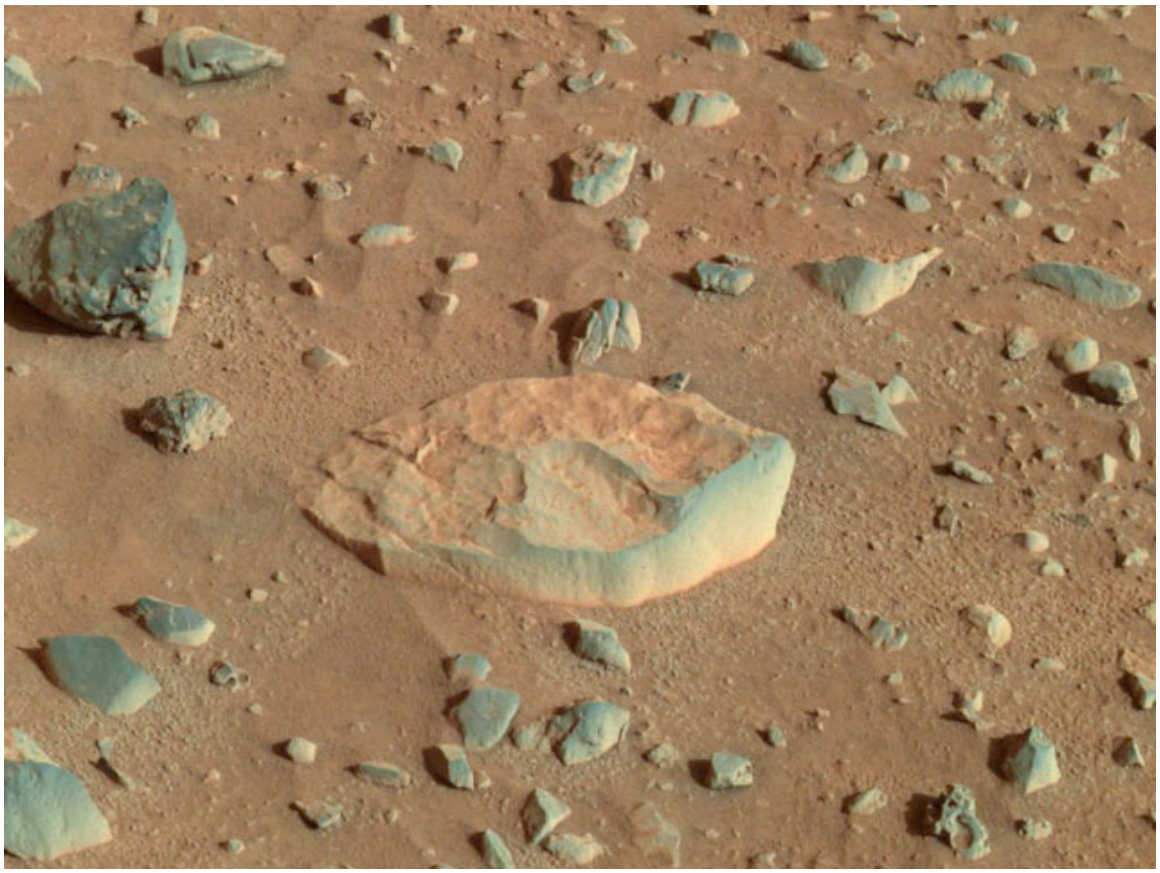
Collisions in 1D.
A review.

- Let's test our understanding of the concepts of linear momentum and collisions by working on the following concept problems:
  - Q13.1
  - Q13.2
  - Q13.3
  - Q13.4



Done for today!
Thursday: collisions in 2D.



White Boat Rock on Mars
Credit: Mars Exploration Rover Mission, JPL, NASA