PHYS 1441 – Section 002
Lecture #17

Monday, Nov. 15, 2010
Dr. Jaehoon Yu

- Linear Momentum Conservation
- Collisions
- Center of Mass
- Fundamentals of Rotational Motion

Today's homework is homework #10, due 10pm, Tuesday, Nov. 23!!

Announcements

- Quiz #5
  - Beginning of the class this Wednesday, Nov. 17
  - Covers: CH 6.5 – CH 7.8
- Two colloquia this week
  - One at 4pm Wednesday, Nov. 17
  - Another at 4pm Friday, Nov. 19

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Mechanically Strong Lightweight Aerogels

Dr. Hongbing Lu

Department of Mechanical Engineering/

UT Dallas

4:00p.m Wednesday November 17, 2010

At SH Rm 101

Abstract:

Monolithic, low-density (down to 1.0 mg/cm3, less than dry air density) 3-D assemblies of nanoparticles (e.g. silica), known as aerogels, are characterized by large specific surface areas and high porosity; they demonstrate low thermal conductivity, low dielectric constants and high acoustic impedance. Traditional aerogels, however, are extremely hygroscopic and fragile materials, limiting their applications to a few specialized environments, such as the materials for capture of hypervelocity particles in space (NASA's Stardust Program) and as integrated structural and thermal insulation materials for electronic boxes aboard planetary vehicles (the Mars Rovers in 1997 and 2004).

The aerogel fragility problem is traced to the weak points in aerogels' framework, the necks connecting neighboring spherical secondary nanoparticles. This problem has been resolved successfully by Leventis (see, for example, Leventis, Acc. Chem. Res. 2007, 40, 874-884) using polymer nanoencapsulation of the skeletal network of inorganic nanoparticles to bridge the nanoparticles and stiffen all the necks. The resulting polymer cross-linked aerogels may combine a high specific compressive strength with the thermal conductivity of Styrofoam.

In collaboration with Leventis we have carried out experiments to characterize the physical, chemical and mechanical properties of this new class of aerogels using a range of techniques including SEM, TEM, SANS. Digital image correlation was used to measure surface deformations. X-ray computed tomography was used to determine the structures for simulations. Material point method (MPM) was used to simulate the deformations to determine the structure-property relationship. Results indicate that both polymer nanoencapsulated aerogels and purely organic aerogels have superior mechanical properties, with the specific energy absorption reaching 192 J/g. The simulation results demonstrate the capability of the MPM in simulations of porous nanostructured materials under compression, experiencing elastic, compaction and densification stages. The work indicates a paradigm in the design of porous nanostructured materials, comprising three degrees of freedom, namely the chemical identity of the nanoparticles, the crosslinking polymer and the nanostruture morphology. Currently technology is evaluated for applications as lightweight multifunctional materials with high-specific strength combined with acoustic attenuation, artificial heart valve leaflets, energetic materials and energy-absorption materials for ballistic impact.

Refreshments will be served in the Physics Lounge at 3:30 pm

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Magnetocalorie Effect in Mn & Fe based Materials

Dr. Ekkes Bruck

Fundamental Aspects of Materials and Energy.
Faculty of Applied Sciences, TU Delft, Mekelweg 15,
2629 JB Delft, the Netherlands

4:00p.m Friday November 19, 2010
At SH Rm 101

Abstract:

Modern society relies on readily available refrigeration. Magnetic refrigeration has three prominent advantages compared to compressor-based refrigeration. First there are no harmful gasses involved, second it may be built more compact as the working material is a solid and third magnetic refrigerators generate much less noise [1].

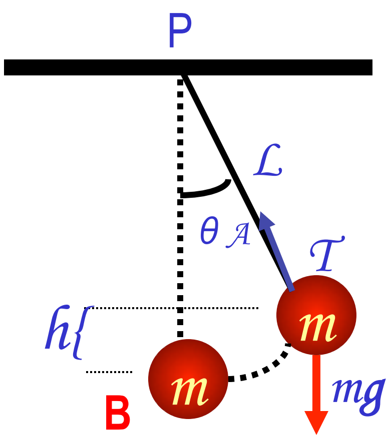
Recently a new class of magnetic refrigerant-materials for room-temperature applications was discovered [2, 3]. These new materials have important advantages over existing magnetic coolants: They exhibit a large magnetocaloric effect (MCE) in conjunction with a magnetic phase-transition of first order. This MCE is, larger than that of Gd metal, which is used in most demonstration refrigerators built to explore the potential of this evolving technology. Especially, materials based on transition elements like manganese and iron appear to be promising for industrial applications. However, if the first order phase-transition is accompanied by large thermal hysteresis, simple refrigeration cycles can not be employed. Also the determination of the MCE for these materials with large hysteresis appears not to be straightforward. For optimal performance of the magnetocaloric devices also the thermal conductivity and the response to mechanical stress need to be tested. We discuss how one may tailor materials to meet the requirements for large MCE in combination with other favorable properties.

As the Curie temperature of transition-metal compounds can easily exceed room temperature it becomes feasible to use them also in power conversion applications. A promising field is the conversion of waste heat to electric power with devices without moving parts.

Reminder: Special Project

1. A ball of mass $\mathcal{M}$ at rest is dropped from the height h above the ground onto a spring on the ground, whose spring constant is k. Neglecting air resistance and assuming that the spring is in its equilibrium, express, in terms of the quantities given in this problem and the gravitational acceleration g, the distance x of which the spring is pressed down when the ball completely loses its energy. (10 points)
2. Find the x above if the ball's initial speed is v_i. (10 points)
3. Due for the project is this Wednesday, Nov. 17.
4. You must show the detail of your OWN work in order to obtain any credit.

Reminder: Special Project II



A ball of mass m is attached to a light cord of length L, making up a pendulum. The ball is released from rest when the cord makes an angle θ_A with the vertical, and the pivoting point P is frictionless.

A) Find the speed of the ball when it is at the lowest point, B, in terms of the quantities given above.

B) Determine the tension T at point B in terms of the quantities given above.

Each of these problem is 10 point. The due date is this Wednesday, Nov. 17.

Extra-Credit Special Project

- Derive the formula for the final velocity of two objects which underwent an elastic collision as a function of known quantities m_1, m_2, v_{01} and v_{02} in page 13 of this lecture note in a far greater detail than the note.
  - 20 points extra credit
- Show mathematically what happens to the final velocities if $m_1=m_2$ and describe in words the resulting motion.
  - 5 point extra credit
- Due: Start of the class Monday, Nov. 29

More on Conservation of Linear Momentum in a Two Body System

From the previous lecture we've learned that the total momentum of the system is conserved if no external forces are exerted on the system.

$$\sum \vec{p} = \vec{p}_2 + \vec{p}_1 = const$$

What does this mean?

As in the case of energy conservation, this means that the total vector sum of all momenta in the system is the same before and after any interactions

Mathematically this statement can be written as

$$\vec{p}_{2i} + \vec{p}_{1i} = \vec{p}_{2f} + \vec{p}_{1f}$$

$$\sum_{system} P_{xi} = \sum_{system} P_{xf} \qquad \sum_{system} P_{yi} = \sum_{system} P_{yf} \qquad \sum_{system} P_{zi} = \sum_{system} P_{zf}$$

This can be generalized into conservation of linear momentum in many particle systems.

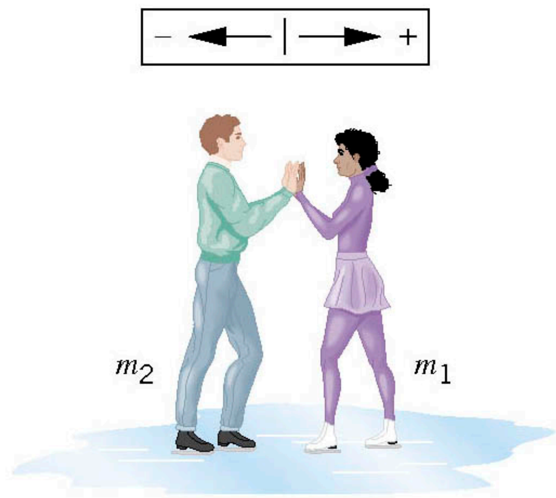
*Whenever two or more particles in an **isolated system** interact, the total momentum of the system remains constant.*

How do we apply momentum conservation?

1. Define your system by deciding which objects would be included in it.
2. Identify the internal and external forces with respect to the system.
3. Verify that the system is isolated.
4. Set the final momentum of the system equal to its initial momentum. Remember that momentum is a vector.

Ex. Ice Skaters

Starting from rest, two skaters push off against each other on ice where friction is negligible. One is a 54-kg woman and one is a 88-kg man. The woman moves away with a speed of +2.5 m/s. Find the recoil velocity of the man.



(a) Before

No net external force → momentum conserved

$$\vec{\mathbf{P}}_{\mathbf{f}} = \vec{\mathbf{P}}_{\mathbf{o}}$$

$$m_1 v_{f1} + m_2 v_{f2} = 0$$

Solve for V_{f2}

$$v_{f2} = -\frac{m_1 v_{f1}}{m_2}$$

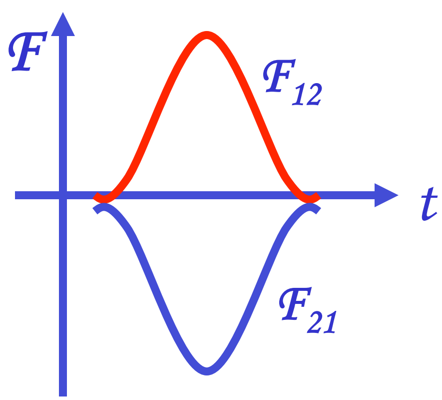
$$v_{f2} = -\frac{(54\text{ kg})(+2.5\text{ m/s})}{88\text{ kg}} = -1.5\text{ m/s}$$

Collisions

Generalized collisions must cover not only the physical contact but also the collisions without physical contact such as that of electromagnetic ones in a microscopic scale.

Consider a case of a collision between a proton on a helium ion.

The collisions of these ions never involve physical contact because the electromagnetic repulsive force between these two become great as they get closer causing a collision.



Assuming no external forces, the force exerted on particle 1 by particle 2, $\mathcal{F}_{21}$, changes the momentum of particle 1 by

$$\boxed{\Delta\vec{p}_1 = \vec{F}_{21}\Delta t}$$

Likewise for particle 2 by particle 1

$$\boxed{\Delta\vec{p}_2 = \vec{F}_{12}\Delta t}$$

Using Newton's 3rd law we obtain

$$\Delta\vec{p}_2 = \vec{F}_{12}\Delta t = -\vec{F}_{21}\Delta t = -\Delta\vec{p}_1$$

So the momentum change of the system in the collision is 0, and the momentum is conserved

$$\Delta\vec{p} = \Delta\vec{p}_1 + \Delta\vec{p}_2 = 0$$

$$\vec{p}_{system} = \vec{p}_1 + \vec{p}_2 = \text{constant}$$

Elastic and Inelastic Collisions

Momentum is conserved in any collisions as long as external forces are negligible.

*Collisions are classified as elastic or inelastic based on whether the **kinetic energy is conserved, meaning whether it is the same** before and after the collision.*

Elastic Collision	*A collision in which **the total kinetic energy and momentum** are the same before and after the collision.*
Inelastic Collision	*A collision in which **the momentum** is the same before and after the collision but not the total kinetic energy .*

Two types of inelastic collisions:Perfectly inelastic and inelastic

Perfectly Inelastic: *Two objects stick together after the collision, moving together with the same velocity.*

Inelastic: *Colliding objects do not stick together after the collision but some kinetic energy is lost.*

Note: Momentum is constant in all collisions but kinetic energy is only in elastic collisions.

Elastic and Perfectly Inelastic Collisions

In perfectly inelastic collisions, the objects stick together after the collision, moving together. Momentum is conserved in this collision, so the final velocity of the stuck system is

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = (m_1 + m_2)\vec{v}_f$$

$$\boxed{\vec{v}_f = \frac{m_1\vec{v}_{1i} + m_2\vec{v}_{2i}}{(m_1 + m_2)}}$$

How about elastic collisions?

In elastic collisions, both the momentum and the kinetic energy are conserved. Therefore, the final speeds in an elastic collision can be obtained in terms of initial speeds as

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

$$\frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2$$

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

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

From momentum conservation above

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

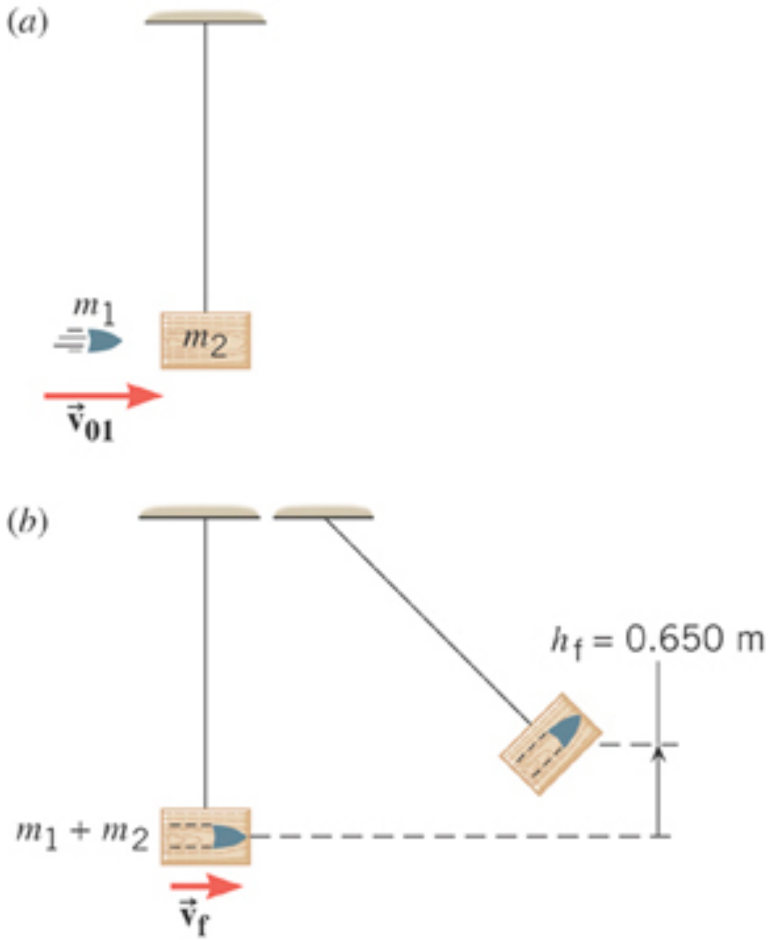
$$\boxed{v_{1f} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)v_{1i} + \left(\frac{2m_2}{m_1 + m_2}\right)v_{2i}}$$

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

What happens when the two masses are the same?

Ex. A Ballistic Pendulum

The mass of the block of wood is 2.50-kg and the mass of the bullet is 0.0100-kg. The block swings to a maximum height of 0.650 m above the initial position. Find the initial speed of the bullet.



What kind of collision? Perfectly inelastic collision

No net external force ➔ momentum conserved

$$m_1 v_{f1} + m_2 v_{f2} = m_1 v_{01} + m_2 v_{02}$$

$$\left(m_1 + m_2\right) v_f = m_1 v_{01}$$

Solve for V_{01}

$$v_{01} = \frac{(m_1 + m_2) v_f}{m_1}$$

What do we not know? The final speed!!

How can we get it? Using the mechanical energy conservation!

Ex. A Ballistic Pendulum, cnt'd

Now using the mechanical energy conservation

$$\tfrac{1}{2}mv^2 = mgh$$

$$\cancel{(m_1 + m_2)} gh_f = \tfrac{1}{2}\cancel{(m_1 + m_2)} v_f^2$$

$$gh_f = \tfrac{1}{2} v_f^2$$

Solve for V_f

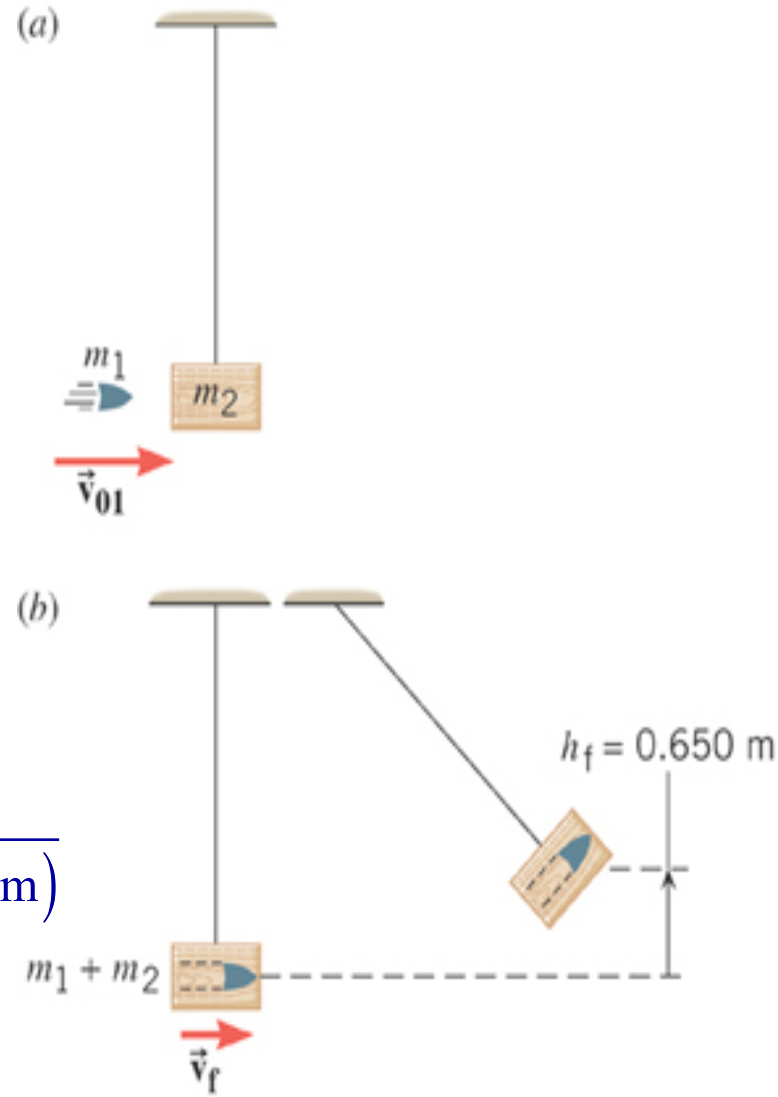
$$v_f = \sqrt{2gh_f} = \sqrt{2\left(9.80\,\mathrm{m/s^2}\right)\left(0.650\ \mathrm{m}\right)}$$

Using the solution obtained previously, we obtain

$$v_{01} = \frac{(m_1 + m_2)v_f}{m_1} = \frac{(m_1 + m_2)\sqrt{2gh_f}}{m_1}$$

$$= \left(\frac{0.0100\ \mathrm{kg} + 2.50\ \mathrm{kg}}{0.0100\ \mathrm{kg}}\right)\sqrt{2\left(9.80\,\mathrm{m/s^2}\right)\left(0.650\ \mathrm{m}\right)}$$

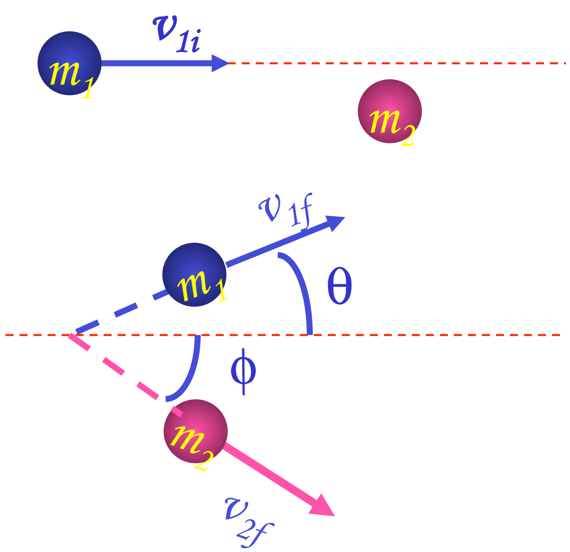
$$= +896\,\mathrm{m/s}$$



Two dimensional Collisions

In two dimension, one needs to use components of momentum and apply momentum conservation to solve physical problems.

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$



x-comp. $m_1 v_{1ix} + m_2 v_{2ix} = m_1 v_{1fx} + m_2 v_{2fx}$

y-comp. $m_1 v_{1iy} + m_2 v_{2iy} = m_1 v_{1fy} + m_2 v_{2fy}$

Consider a system of two particle collisions and scatters in two dimension as shown in the picture. (This is the case at fixed target accelerator experiments.) The momentum conservation tells us:

$$m_1\vec{v}_{1f} + m_2\vec{v}_{2f} = m_1\vec{v}_{1i}$$

$$m_1 v_{1ix} = m_1 v_{1fx} + m_2 v_{2fx} = m_1 v_{1f}\cos\theta + m_2 v_{2f}\cos\phi$$

$$m_1 v_{1iy} = 0 = m_1 v_{1fy} + m_2 v_{2fy} = m_1 v_{1f}\sin\theta - m_2 v_{2f}\sin\phi$$

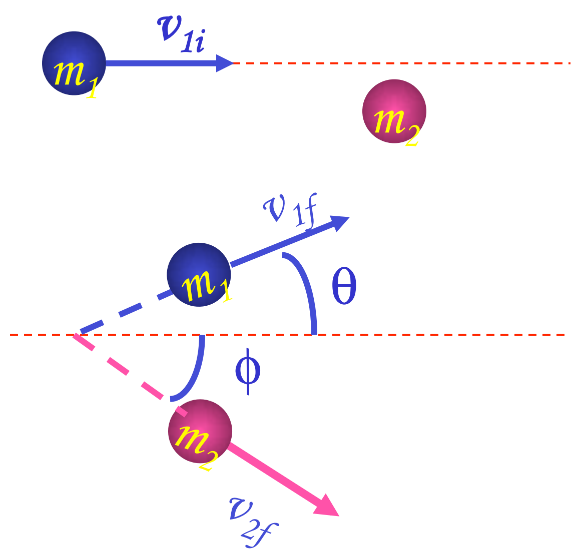
And for the elastic collisions, the kinetic energy is conserved:

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

What quantities do you think we can learn from these relationships?

Example for Two Dimensional Collisions

Proton #1 with a speed 3.50x10^5 m/s collides elastically with proton #2 initially at rest. After the collision, proton #1 moves at an angle of 37^o to the horizontal axis and proton #2 deflects at an angle f to the same axis. Find the final speeds of the two protons and the scattering angle of proton #2, ϕ.



Since both the particles are protons $m_1=m_2=m_p$.

Using momentum conservation, one obtains

x-comp. $$m_p v_{1i} = m_p v_{1f}\cos\theta + m_p v_{2f}\cos\phi$$

y-comp. $$m_p v_{1f}\sin\theta - m_p v_{2f}\sin\phi = 0$$

Canceling m_p and putting in all known quantities, one obtains

$$v_{1f}\cos 37^\circ + v_{2f}\cos\phi = 3.50\times10^5 \quad (1)$$

$$v_{1f}\sin 37^\circ = v_{2f}\sin\phi \quad (2)$$

From kinetic energy conservation:

$$\left(3.50\times10^5\right)^2 = v_{1f}^2 + v_{2f}^2 \quad (3)$$

Solving Eqs. 1-3 equations, one gets

$$v_{1f} = 2.80\times10^5\, m/s$$
$$v_{2f} = 2.11\times10^5\, m/s$$
$$\phi = 53.0^\circ$$

Do this at home☺