Physics 141.
Lecture 16.

Projectile motion – a great homework assignment!


Physics 141.
Lecture 16.

• Course Information.
• Quiz.
• Concept test.
• Topics to be discussed today:
  • Two-dimensional collisions - elastic and inelastic.
  • Using collisions to explore the microscopic world.

Course Information.

• Laboratory experiment # 5 will take place on Monday November 14 in the May room (data collection) in Wilson Commons and on November 21 in B&L 407 (video analysis).
  • The focus of experiment # 5 will be collisions between you and a colleague.
  • The experiment requires empty Wegmans soda cans.
  • I will distribute 12-packs of soda in class during the week of November 7. You are supposed to get rid of the soda, by drinking it for example, and take the empty and rinsed soda cans to your laboratory session on Monday November 14. Note: cans need to be unscratched and not dented.
• Homework:
  • Homework set # 7 is due on Friday 11/4 at noon.
• Collisions (Chapter 10):
  • Elastic collisions of macroscopic objects.
  • Inelastic collisions of macroscopic objects.
Results Exam # 2.

How good was your prediction?

???
The Personal Response System (PRS).
Quiz.

Physics 141.
Concept Test.

- Let us practice what we have learned so far.
- This test allows me to assess your understanding of the material, but will not be effect your Physics 141 grade.
- Your PRS will be used to enter your answers.

Collisions in two or three dimensions.

- Collisions in two or three dimensions are approached in the same way as collisions in one dimension.
- The x, y, and z components of the linear momentum must be conserved if there are no external forces acting on the system.
- The collisions can be elastic or inelastic.
Collisions in two dimensions.
Elastic collisions.

Collisions in two or three dimensions.
Example problem.

- A 20-kg body is moving in the direction of the positive x-axis with a speed of 200 m/s when, owing to an internal explosion, it breaks into three parts. One part, whose mass is 10 kg, moves away from the point of explosion with a speed of 100 m/s along the positive y-axis. A second fragment, with a mass of 4 kg, moves along the negative x-axis with a speed of 500 m/s.
  - What is the speed of the third (6 kg) fragment?
  - How much energy was released in the explosion (ignore gravity)?

Collisions in two or three dimensions.
Example problem.

- There are no external forces and linear momentum must thus be conserved.
- Conservation of linear momentum along the x axis requires
  \[ M \vec{v}_f = m_1 \vec{v}_1' + m_2 \vec{v}_2' \]
- Conservation of linear momentum along the y axis requires
  \[ 0 = m_1 \vec{v}_1' \sin \theta + m_2 \vec{v}_2' \sin \theta \]
Collisions in two or three dimensions.
Example problem.

- What do we know:
  - Speed and direction of mass \( M \)
  - Speed and direction of mass 1
  - Speed and direction of mass 2

- What do we need to know:
  - Speed and direction of mass 3

Since we have two equations with two unknown, we can find the speed and direction of mass 3.

Once we know the speed of mass 3, we can calculate the amount of energy released.

Collisions in two or three dimensions.
Example problem.

- Our two equations can be rewritten as
  \[
  m_1 v_1 \cos \theta_1 = M v_f \cos \theta_2
  \]
  \[
  m_1 v_1 \sin \theta_1 = m_2 v_2
  \]
  We can solve this equation by squaring each equation and adding them together:
  \[
  (m_1 v_1)^2 = (M v_f \cos \theta_2)^2 + (m_2 v_2)^2
  \]
- This equation tells us that \( v_2 = 1.014 \) m/s.
- The energy release is 3.23 MJ.

3 Minute 47 Second Intermission.

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let’s take a 3 minute 47 second intermission.
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWorK problem.
Ernest Rutherford.
Probing the nucleus using collisions.

- Born in 1871 in New Zealand.
- Received his BA in 1892 and his MA in 1893 from Canterbury College.
- Rutherford won a scholarship which provided further study in England. He continued his study in 1895 in Cambridge.
- In 1898 Rutherford was appointed to the chair of physics at McGill (Montreal).
- In 1907 he returned to England to the University of Manchester.

Ernest Rutherford (1871-1937)

Ernest Rutherford.
Probing the nucleus using collisions.

- Ernest Rutherford won the 1908 Nobel Prize for Chemistry for his studies of the disintegration of elements.
- Rutherford's most important contribution was his nuclear theory of the atom.
- The results of his experiment could only be understood if it was assumed that the positive charge of the atom was concentrated in a very small volume within the atom ($10^{-15}$ m instead of $10^{-10}$ m).

Ernest Rutherford (1871-1937)

The Thomson model of the atom.

- At the end of the 19th century it was believed that the Thomson model provided a good description of the atom.
- In the Thomson model, it was assumed that the positive charge of the atom was distributed evenly over the volume of the atom.
- The electrons of the atom were distributed throughout the volume of the atom.
- Using Coulomb's law Rutherford determined that the maximum deflection of an alpha particle by a gold atom is less than 0.02°.

Joseph John Thomson. Received the Nobel prize of Physics in 1906: for the discovery of the electron.

http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/rutsca3.html
The Rutherford experiment.
The observation of large angle scattering.

Using Rutherford scattering to measure the size of the nucleus.

• Scattering of alpha particles from nuclei was an important tool to study the nuclear dimension.
• Deviations from Rutherford scattering are expected when the alpha particle reaches the nucleus (that is, the initial energy can overcome Coulomb repulsion).

Collisions at relativistic energies.

• When the energies of the collision partners are larger than their rest mass, we need to treat the collision relativistically.
• For an elastic collision, the following three equations must be satisfied:

\[ p_1 = p_3 \cos \theta + p_4 \cos \phi \]
\[ 0 = p_3 \sin \theta - p_4 \sin \phi \]
\[ \sqrt{(p_1c)^2 + (m_1c^2)^2} + \sqrt{(p_3c)^2 + (m_2c^2)^2} = \sqrt{(p_3c)^2 + (m_3c^2)^2} + \sqrt{(p_4c)^2 + (m_4c^2)^2} \]
Collisions at relativistic energies.

- The relativistic relations are also correct for photons and other massless particles.
- For massless particles the relation between energy and momentum is $E = p_c$.
- The relativistic equations take into consideration the effect of the changes in mass between the initial and final configuration.
- If the particles are excited as a result of the interaction, the loss of mechanical energy to excitation energy needs to be taken into consideration in our studies.

Deviations from conservation of linear momentum and energy?

- The study of beta decay of nuclei in the beginning of the 20th century generated many questions about the validity of the conservation laws.
- In beta decay, a neutron in a nucleus is changed into a proton (or vice-versa) and as a result the nature of the element changes (remember: the number of protons determines the element).
- Detailed measurements of the spectrum of the electrons (or positrons) emitted during beta decay revealed problems with conservation of linear momentum and conservation of energy (even after taking into account the change in energy due to differences in atomic mass).

A letter from W. Pauli (12/4/1930) proposing the existence of what we now call a neutrino.

Dear Archibald ladies and Gentlemen: As the bearer of these lines to which I gravely ask you to listen, will explain to you in more detail how because of the "wrong" statistics of the N and L.P. nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the law of conservation of energy. Namely, the possibility that there could exist in the nuclei electrically neutral particles, that one wishes to call neutrons, which have spin 1/2 and obey the exclusion principle and which further offer from light quanta that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron-mass and in any event not larger than 0.01 proton masses. The continuous beta spectrum would then become understandable by the assumption that in beta decay a neutron is emitted in addition to the electron such that the sum of the energies of the neutron and the electron is constant. I agree that my remedy could seem incredible because one should have seen those neutrons very early if they really exist. But only the one who does can win and the difficult situation, due to the continuous structure of the beta spectrum, is lighted by a remark of my honored predecessor, Mr. Debey, who told me recently in Brussels: "Oh, it's well better not to think about it at all, like new taxes!" From now on, every solution to the issue must be discussed. Thus, dear radioactive people, look and judge. Unfortunately, I cannot appear in Tubingen personally since I am indispensable here in Zurich because of a talk on the right of 07 December. With my best regards to you, and also to Mr. Bach. Your humble servant, W. Pauli

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Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 20
Searching for the neutron, and finding one that is too heavy.

1930: W. Pauli proposes the existence of the neutron.
1932: J. Chadwick discovers the neutron (it is too heavy!)

In 1953 Reines and Cowan detected neutrinos generated by a nuclear reactor.

Since 1953 we have learned a lot about neutrinos.

- Neutrinos come in different flavors (electron, muon, and tau neutrinos): there is one neutrino for each lepton flavor.
- Neutrinos actually have (a very small) mass.
The bubble chamber picture of the first omega-minus. An incoming K meson interacts with a proton in the liquid hydrogen of the bubble chamber and produces an omega-minus, a K0 and a K+ meson which all decay into other particles. Neutral particles which produce no tracks in the chamber are shown by dashed lines. The presence and properties of the neutral particles are established by analysis of the tracks of their charged decay products and application of the laws of conservation of mass and energy.

Done for today! Next: rotational and rolling motion.