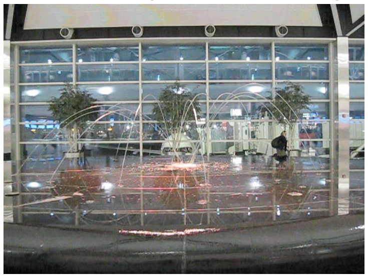
Physics 141.
Lecture 16.

Projectile motion – a great homework assignment!



Detroit, 10/23/2014. Video by F. Wolfs Jr.

Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 1

1

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.

Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 2

2

Course Information.

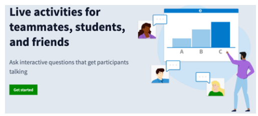
- Laboratory experiment # 5 will take place on Monday November 13 in the Spurrier Gym and on November 20 in B&L 407 (video analysis).
  - The focus of experiment # 5 will be collisions between you and a colleague.
  - The experiment requires empty Wegmans sparkling water cans.
  - I will distribute 12-packs of sparkling water cans in class during the week of November 6. You are supposed to get rid of the sparkling water, by drinking it for example, and take the empty and rinsed cans to your laboratory session on Monday November 13. Note: cans need to be unscratched and not dented.
- Homework:
  - Homework set # 6 is due on Friday 11/3 at noon.

Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 3

3

Quiz lecture 16.
PollEv.com/frankwolfs050

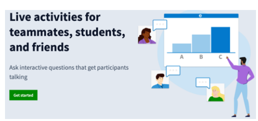
- The quiz today will have four questions.
- I will collect your answers electronically using the Poll Everywhere system.
- The answers for each question will be entered in sequence (first 30 s for question 1, followed by 30 s for question 2, etc.).



4

Concept test lecture 16.
PollEv.com/frankwolfs050

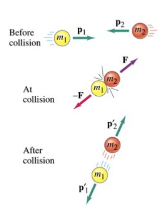
- The concept test today will have two questions.
- I will collect your answers electronically using the Poll Everywhere system.
- After submitting your answer, I will give you time to discuss the question with your neighbor(s) before submitting a new answer.



5

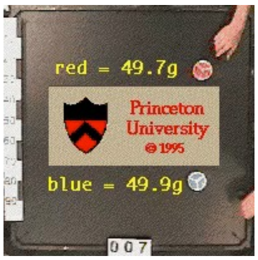
Collisions in two or three dimensions.

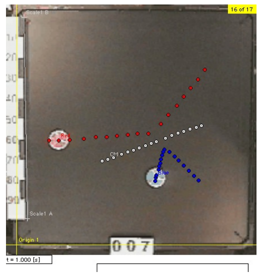
- Collisions in two or three dimensions are approached in the same way as collisions in one dimension.
- The x, y, and z components of the linear momentum must be conserved if there are no external forces acting on the system.
- The collisions can be elastic or inelastic.



6

Collisions in two dimensions.
Elastic collisions.



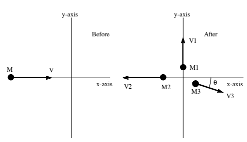


Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 7

7

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)?



Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 8

8

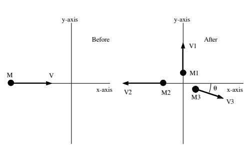
Collisions in two or three dimensions.
Example problem.

- There are no external forces and linear momentum must thus be conserved.
- Conservation of linear momentum along the x axis requires

$$MV = m_3 v_3 \cos\theta_3 - m_2 v_2$$

- Conservation of linear momentum along the y axis requires

$$0 = m_1 v_1 - m_3 v_3 \sin\theta_3$$

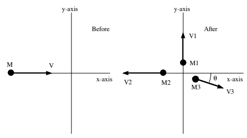


Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 9

9

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.



Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 10

10

Collisions in two or three dimensions. Example problem.

- Our two equations can be rewritten as

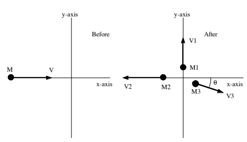
$$m_3 v_3 \cos\theta_3 = MV + m_2 v_2$$

$$m_3 v_3 \sin\theta_3 = m_1 v_1$$

- We can solve this equation by squaring each equation and adding them together:

$$\left(m_3 v_3\right)^2 = \left(MV + m_2 v_2\right)^2 + \left(m_1 v_1\right)^2$$

- This equation tells us that v_3 = 1,014 m/s.
- The energy release is 3.23 MJ.



Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 11

11

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.

Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 16, Page 12

12

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 her returned to England to the University of Manchester.

Ernest Rutherford
(1871-1937)

13

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).

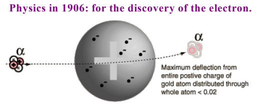
Ernest Rutherford
(1871-1937)

14

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°.

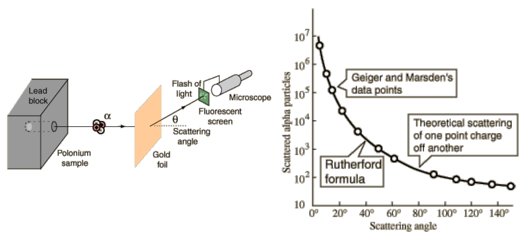
Joseph John Thomson. Received the Nobel prize of Physics in 1906: for the discovery of the electron.



http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/rutsca3.html

15

The Rutherford experiment. The observation of large angle scattering.

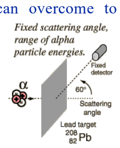


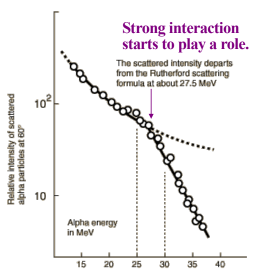
http://hyperphysics.phy-astr.gsu.edu/hbase/rutsca.html

16

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 the alpha particle reaches the nucleus (that is the initial energy can overcome to Coulomb repulsion).





http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/rutsca3.html

Eisberg, R. M. and Porter, C. E., Rev. Mod. Phys. 33, 190 (1961)

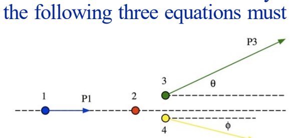
17

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 collisions, the following three equations must be satisfied:

$$p_1 = p_3 \cos\theta + p_4 \cos\phi$$

$$0 = p_3 \sin\theta - p_4 \sin\phi$$



$$\sqrt{(p_1c)^2 + (m_1c^2)^2} + m_2c^2 = \sqrt{(p_3c)^2 + (m_3c^2)^2} + \sqrt{(p_4c)^2 + (m_4c^2)^2}$$

18

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 $E = pc$.
- 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.

19

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).

20

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

Dear Radioactive Ladies and Gentlemen, As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, how because of the "wrong" statistics of the N and Li^6 nuclei and the continuous beta spectrum, **I have hit upon a deseperate 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 I wish to call neutrons, which have spin 1/2 and obey the exclusion principle and which further differ from light quanta in 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 earlier if they really exist. But only the one who dare can win and the difficult situation, due to the continuous structure of the beta spectrum, is lighted by a remark of my honoured predecessor, Mr Debye, who told me recently in Bruxelles: "Oh, It's well better not to think to this 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 ball on the night of 6/7 December. With my best regards to you, and also to Mr Back.Your humble servant. W. Pauli

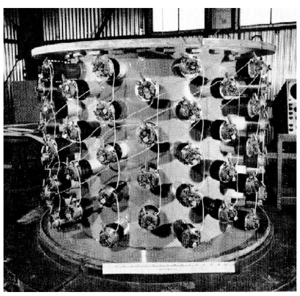
21

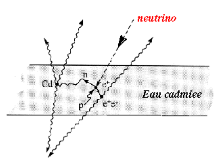
Searching for the neutron, and finding one that is too heavy.

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.



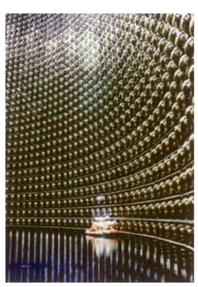


Since 1953 we have learned a lot about neutrinos.

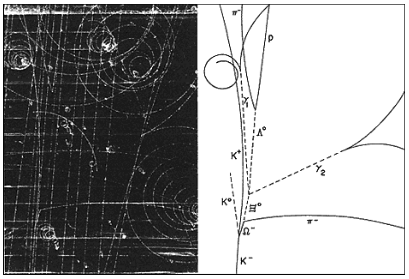
- Neutrinos come in different flavors (electron, muon, and tau neutrinos): there is one neutrino for each lepton flavor.
- Neutrinos actually have (a very small) mass.

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge	Flavor	Approx. Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	−1	d down	0.006	−1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	−1	s strange	0.1	−1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	−1	b bottom	4.3	−1/3



Applying conservation of linear momentum and energy.



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 K_0 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.

Credit: Brookhaven National Laboratory, NY, USA
http://www.bnl.gov/bnlweb/history/Omega-minus.asp

25

Done for today! Next: rotational and rolling motion.

Photo taken on 2013-10-8 by Patkee

26