

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Physics

Physics 8.01T

Fall Term 2004

Problem Set 2: Kinematics in One and Two Dimensions

Available on-line September 10; Due: September 21 at 4:00 p.m.

Please write your name, class section, table and group number, and the name of the instructor on the top right corner of the first page of your homework solutions. Please place your solutions in the box labeled with your instructor and your table number.

Sept 10

Hour One: Kinematics: One Dimensional Motion, Velocity and Acceleration

Reading: YF 2.1-2.6

Problem Set 1: Due Tues Sept 14 at 4:00 pm.

Sept 13

Hour One: Experiment 1: Introducing Data Studio; One Dimensional Motion, Velocity and Acceleration; Error Analysis and Statistics.

Reading: Experiment 1

Hour Two: Problem Solving Session 1: One Dimensional Motion

Reading: YF 2.4-2.6

Sept 15

Hour One: Kinematics: Two Dimensional Motion, Velocity and Acceleration

Reading: YF 3.1-3.3

Hour Two: Experiment 2: Projectile Motion

Reading: Experiment 2

Sept 17

Hour One: Problem Solving Session 2: Projectile Motion

Reading: YF 3.3

Problem Set 2: Due Tues Sept 21 at 4:00 pm.

Sept 20

Hour One: Newton's Laws of Motion: Force, Mass, and Acceleration with Experiment 3: Force Laws and $F = ma$, Hooke's Law.

Reading: YF 4.1-4.6, Experiment 3

Hour Two: Problem Solving Session 3: Vectors in Physics; Principle of Relativity: Relative Inertial Frames: Newton's First Law
Reading: YF 1.8-1.11; 3.5

Sept 22

Hour One: Applying Newton's Laws of Motion
Reading: YF 5.1-5.3, 5.5

Hour Two: Experiment 3: Modeling Forces

Sept 24

Hour One: Problem Solving Session 4: Newton's Laws of Motion; Spring Forces, Tension.
Reading: YF 5.1-5.3, 5.5

Problem Set 3: Due Tues Sept 28 at 4:00 pm.

Problem 1 (*measurement of g*)

The acceleration of gravity can be measured by projecting a body upward and measuring the time that it takes to pass two given points in both directions. Suppose a friend throw a ball straight up outside your window. You measure the distance h from the bottom of the lower pane of glass to the top of the upper pane of glass. You measure the time interval T_A the body takes to cross first rise past the bottom of the lower pane of glass and then drop past the same line on the way down. You also measure the time interval T_B the body takes to disappear past the top of the upper pane of glass and then reappear past the same line on the way down. Assume that the acceleration is constant, (negligible air resistance), the problem is to find an expression for the acceleration of the body in terms of the measured quantities.

- a) Describe the strategy you have chosen for solving this problem. You may want to consider the following issues. Where do your measured quantities appear on a plot of height vs. time? What type of coordinate system will you choose? Where is a good place to choose your origin?
- b) Find an expression for the acceleration of the body in terms of the measured quantities.

Problem 2 *One dimensional kinematics: track event*

During a track event two runners, Bob, and Jim, round the last turn and head into the final stretch with Bob 2.0 m in front of Jim. They are both running with the same velocity $8.0\text{ m} - \text{s}^{-1}$. When the finish line is $4.8 \times 10^1\text{ m}$ away from Jim, Jim accelerates at $1.0\text{ m} - \text{s}^{-2}$ until he catches up to Bob. Jim then continues at a constant speed until he reaches the finish line.

- a) Describe the strategy you have chosen for solving this problem
- b) How long did it take Jim to catch Bob?
- c) How far did Jim still have to run when he just caught up to Bob?
- d) How long did Jim take to reach the finish line after he just caught up to Bob?

Bob starts to accelerate when Jim just catches up to him, and accelerates all the way to the finish line and crosses the line exactly when Jim does. Assume Bob's acceleration is constant.

- e) What is Bob's acceleration?
- f) What is Bob's velocity at the finish line? Who is running faster?

Problem 3: (projectile motion, softball)

A softball is hit over a third baseman's head. The third baseman, as soon as it is hit, turns around and runs straight back with an average velocity of $v_1 = 7.0\text{m} \cdot \text{s}^{-1}$ for a time interval $\Delta t = 2.0\text{s}$ and catches the ball at the same height it left the bat. The third baseman was initially $d_1 = 1.8 \times 10^1\text{m}$ from home plate.



- Describe the strategy you have chosen for solving this problem. You may want to consider the following issues. What type of coordinate system will you choose? Where is a good place to choose your origin?
- What was the initial speed and angle of the softball when it left the bat?
- Write down a vector expressions for the position and velocity of the softball 0.1 s before the ball was caught?

Problem 4: (Experiment 3 Modeling Forces Three Pre-Lab Question)

In your *Experiment 3: Modeling Forces*, you will measure the magnitude of the force $|\vec{F}|$ between small magnets as a function of the distance x between the centers of the magnets.

- Suppose the magnitude of the force decreases exponentially according to $|\vec{F}| = ae^{-bx}$ where a and b are constants. Suppose you plot the natural logarithm of the magnitude of the force, $\ln|\vec{F}|$, vs. the distance x between the centers of the magnets. What information can you deduce from the slope of this plot?
- Suppose for some range of separation of the magnets, the magnitude of the force obeys a power law, $|\vec{F}| = cx^d$ where c and d are constants. Describe a graphical procedure which we enable you to determine the power law constant d .

Problem 5: Experiment 2 Projectile Motion Data Analysis

a) Did your group perform the Falling Ball Experiment or the Projected Ball Experiment?

Part A: Measurement of Exit Velocity

1) For either the falling or projected ball experiment, measure the angle of the tube. Make a measurement of the height of the exit point of the tube above the ground.

Angle = _____, Uncertainty = _____.

Height = _____, Uncertainty = _____.

What are the uncertainties in these measurements?

Data Table I for Exit Velocity

Trial	Angle [degrees]	Vertical displacement [m]	Horizontal displacement [m]	Calculated Exit Velocity based on theory [$\text{m} \cdot \text{s}^{-1}$]	Measured Pulse width ΔT [s]	Calculated Exit Velocity based on pulse width [$\text{m} \cdot \text{s}^{-1}$]
1						
2						
3						
Mean						

2) **Run three trials** of the ball undergoing projectile motion at the same angle. For each trial, measure the horizontal displacement between the point where the ball hits the ground and the exit point of the tube.

3) Use the results of your three measurements, height above ground, horizontal distance to impact, and angle, to calculate the magnitude of the exit velocity of the ball. What are the errors in these measurements? You may use as a measure of your error the average deviation of your measurements. See *Class Notes: Error Analysis*.

4) When the ball exits the tube it crosses the photogate. Based on your calculation for the exit velocity, what is the time interval ΔT the ball takes to travel a distance $D = 12 \text{ mm}$ (equal to the diameter of the ball)?

5) When the ball crosses the photogate, the photogate circuitry records the voltage as a function of time which you can graph with the Data Studio software. From the graph, record the pulse

width (corresponding to the time interval it takes the ball to cross the photogate) at half the maximum voltage height.

What are the errors in these measurements? You may use as a measure of your error the average deviation of your measurements. See *Class Notes: Error Analysis*.

6) How does the time interval that you calculated in part 4), compare to the average time interval you measured in part 5)? Briefly explain the physical basis for any discrepancies between your calculations and measurements.

7) Let $D = 12\text{ mm}$ is the diameter of the ball and ΔT is the time interval that the ball travels its diameter when it exits the tube. Based on your measurements in part 5), calculate the average exit velocity, $\bar{v}_{\text{exit}} = D / \Delta T$.

8) Compare your result in part 7) to the calculation of the exit velocity based on measurements of height above ground, horizontal distance to impact, and angle in part 3). How do your results compare?

9) What is the major source of error in this experiment?

Part B: Measurement of the Gravitational Constant

10) If you only made one experiment (three trials) you can use your three measurements above but now only use your photogate calculation for the exit velocity. Enter your data in the table below. If you repeated the experiment (three trials) at a different angle, use your second set of data with your photogate calculation for the exit velocity.

Data Table II for Gravitational Constant

Trial	Angle [degrees]	Vertical displacement [m]	Horizontal displacement [m]	Measured Pulse width ΔT [s]	Photogate Exit Velocity $\bar{v}_{\text{exit}} = D / \Delta T$ [$\text{m} \cdot \text{s}^{-1}$]	Calculated gravitational constant g [$\text{m} \cdot \text{s}^{-2}$]
1						
2						
3						
Mean						

11) Based on your mean values, calculate a mean value for the gravitational constant \bar{g} .

12) Based on your best estimate for the most significant errors in this experiment, what is an estimate for the fractional error $\Delta g / \bar{g}$ for your measurement of the gravitational constant?