Physics for Poets
Midterm 1 – 5 October, 2011

SOLUTIONS

INSTRUCTIONS (read them!)

- Do all work that you want graded in a bluebook. The graders will not look at the exam sheets.
- Write your name clearly on the front of all your bluebooks
- Number your bluebooks (1-of-2, 2-of-2) if you use more than one so that the graders don’t miss some of your work
- Total point values for each question and a breakdown of how much each part is worth are given with the question.
- This exam is closed book. You are not allowed a note sheet. Useful formulas are given below.
- If you have questions during the exam, please ask the proctors.
- Hand in your bluebook(s) and the exam sheet at the front of the room when you have finished.

USEFUL FORMULAS

Geometry/Trigonometry

- \( v^2 = v_x^2 + v_y^2 \)
- \( v_x = v \cos \theta \)
- \( v_y = v \sin \theta \)
- \( \tan \theta = \frac{v_y}{v_x} \)

Constants

- \( g = 9.8 \text{ m/s}^2 \) acceleration of gravity near earth

Motion Equations

- \( \langle a \rangle = \frac{\Delta v}{\Delta t} \)
- \( \langle v \rangle = \frac{\Delta x}{\Delta t} \)
- \( \Delta x = v_o \Delta t + \frac{1}{2} a \Delta t^2 \) constant acceleration

Force & Momentum

- \( p = m v \) definition of momentum
- \( F_{\text{tot}} = m a = \frac{dp}{dt} \) Newton’s 2nd Law
- \( F_{f,k} = \mu_k N \) Kinetic Friction
- \( F_{f,s}^{\text{max}} = \mu_s N \) Static Friction
PROBLEM 1: Multiple Choice [10 pts – 1 pt each]

i. Which of the following is an assumption in Galileo’s theory of falling motion that had to be proved experimentally
   a. the acceleration of all falling objects near earth is a constant
   b. \( a = \Delta v / \Delta t \)
   c. gravity is the cause of acceleration
   d. the Earth moves around the Sun

   Answer: a)
   b) is a definition, d) is unrelated to Galileo's theory of motion and c) (the whys of motion) was something Galileo did not set out to answer.

ii. An outfielder throws a baseball to home base with an initial velocity \( v_o \). This initial velocity has horizontal (\( v_{ox} \)) and vertical (\( v_{oy} \)) components. Neglect air resistance. What is the horizontal speed of the ball when the catcher catches it:
   a. less than \( v_{ox} \)
   b. greater than \( v_{ox} \)
   c. the same as \( v_{ox} \)

   Answer: c)
   According to the Principle of Inertia, the speed of the ball in the horizontal direction does not change since there are no forces acting horizontally.

iii. What will be the horizontal speed of the ball as the catcher catches it in the real world (including air resistance):
   a. less than \( v_{ox} \)
   b. greater than \( v_{ox} \)
   c. the same as \( v_{ox} \)

   Answer: a)
   Air resistance always slows down motion.

iv. Neglecting air resistance, what is the acceleration of the ball at the highest point on its trajectory?
   a. zero
   b. 9.8 m/s\(^2\) downward
   c. totally horizontal
   d. none of the above

   Answer: b)
   The acceleration of gravity is constant near the surface of the earth (as Galileo showed).
v. If momentum is conserved in a collision between two objects (the system), then which of the following is always true?
   a. The net external force acting on the system is zero.
   b. There are no internal forces acting in the system.
   c. The momenta of each of the two objects is unchanged by the collision.
   d. The kinetic energy (vis viva) of the system is also conserved.

Answer: a)
Momentum is only conserved in a system on which no total external force acts. Internal forces cancel in this calculation, the momentum of each object participating in the collision certainly and kinetic energy is only conserved in a sub-set of all collisions (elastic collisions). So b,c,d) are incorrect.

vi. If I am standing on a scale in an elevator that is falling freely near the Earth's surface (accelerating downward at 9.8 m/s²), how will my weight, as measured by the scale, compare with my normal weight (measured by a scale at rest in my bathroom)?
   a. it will be slightly less than my normal weight
   b. it will be the same as my normal weight
   c. it will be slightly greater than my normal weight
   d. it will be zero

Answer: d)
As we showed in Homework 2, if your acceleration is g (downward) then the normal force of the scale on you must be zero. Hence the scale will read 0.

vii. A block sits at rest on an inclined plane. If, after I increase the angle that the incline makes with the horizontal, but the block remains motionless, what happens to the magnitude of the force of friction exerted on the block?
   a. it increases
   b. it decreases
   c. it stays the same

Answer: a)
Since the component of the force of gravity acting down the incline increases as the angle increases, the force of (static) friction must also increase in order to keep the block stationary.

viii. The coefficient of static friction between two objects is:
   a. less than the coefficient of kinetic friction
   b. greater than the coefficient of kinetic friction
   c. equal to the coefficient of kinetic friction

Answer: b)
This is why it takes more force to start an object moving than it does to keep an object moving against friction.
ix. A large, heavy truck collides with a small, light car. Which of them exerts the largest force on the other?
   a. The force of the truck on the car is largest.
   b. The force of the car on the truck is largest.
   c. The two forces above are equal.
   d. Not enough information is given to be able to answer.

Answer: c)  
This is just Newton's 3\textsuperscript{rd} Law.

x. In the collision of the previous problem, assume that the car and truck come to rest together. Which of the two experiences the largest acceleration during this process?
   a. The truck
   b. The car
   c. Both accelerations are equal
   d. Not enough information is given to be able to answer.

Answer: b)  
Since $F = m a$, the car, having the smaller $m$, will have the larger $a$.  


PROBLEM 2 [25 pts]

a. [5] What was one of the major philosophical differences between the approaches of Aristotle and Galileo to the study of motion?
Answer: There are four main possibilities here. Mentioning any one of them is sufficient to get full credit for this part.
   i. Aristotle was interested in the question “why do things move” while Galileo sought to answer “how things move”.
   ii. As a corollary to answer i), Aristotle did not attempt to make many predictions about how things would move in the real world, while that was the main motivation of Galileo’s work.
   iii. Galileo introduced the concept of designing specific experiments to test his predictions while Aristotle was content to simply observe things as they existed naturally in the real world in order to support his theories.
   iv. Galileo also used the principles of abstraction and approximation (you don’t have to mention this by name) which allowed him to consider motion in the simple case where it is unaffected by the medium through which a body is moving. Aristotle believed that the medium was essential to understanding an object’s motion.

Answer: Although both Aristotle and Galileo used assumptions as the starting point for the chain of reasoning leading to their conclusions, Aristotle generally designed his assumptions to be as obvious as possible and therefore did not call them into question. Galileo’s purpose, on the other hand, was precisely to decide (through experiment) whether his initial assumptions were correct or not.

c. [8] What was one of the main non-religious arguments that people used against the idea that the earth moves around the sun.
Answer: If you jump up in the air, the earth should move underneath you while you’re no longer in contact with it. Similar arguments should apply to birds or anything you throw directly upward.
d. [8] What argument did Galileo use to show that this reasoning was not correct? You can either discuss the physical principle he applied to the problem or describe a counter-example that he used which showed a real-world situation where the case made in part c) did not work.

Answer: The two possibilities for answering this question are the following.

i. **Physical Principle**: Galileo used what was later called the Principle of Inertia (you don’t have to mention this by name) to correctly describe this situation. This principle states that an object continues in uniform motion (i.e. its velocity vector does not change) as long as it is not subjected to an external influence (force). Since no force is acting on you in the horizontal direction after you jump, your motion continues as before – the same as that of the earth under you.
   
   Note: this argument also relies on the principle of superposition, but you don’t have to mention that to get full credit.

ii. **Counter-Example**: If you drop a ball from the mast of a moving ship, the ball will land at the base of the mast (because it shares the ship’s motion) not somewhere behind the ship as you would expect if the ship had to keep pushing it in order for it to continue to move horizontally.
PROBLEM 3 [20 pts]

a. [8] We discussed four fundamental assertions that Galileo made in his description of motion. Describe two of them and discuss how each differed from the Aristotelian view.

Answer: Each of the four assertions are described below.

i. In the absence of a resistive medium (i.e. in vacuum), all objects fall in the same way.
   In Aristotle’s view, the medium was critical to understanding the motion of objects – it was tied up with why the object moved in the first place. Additionally, Aristotle did not believe that a true vacuum could exist. Alternatively, you can get credit for this part of the problem if you mention that Aristotelians believed that heavier bodies fall faster than lighter bodies.

ii. In equal time intervals, falling bodies gain equal increments of velocity. In other words, the acceleration of falling motion is constant near the surface of the earth.
   Aristotle made no attempt to make such precise predictions in his theories of motion.

iii. In the absence of disturbances, an object will continue to move at constant speed on a horizontal surface. (Principle of inertia.)
   The Aristotelian view was that the “natural” state of horizontal motion was to be at rest. Thus, an initially moving object would quickly slow down and stop to achieve this natural state.

iv. Independent influences act independently on a body. (Principle of superposition.)
   Another acceptable answer to this part of the question is that the vertical and horizontal components of motion are independent of each other.
   In Aristotle’s view, only the aggregate motion of an object could be considered. One could not treat horizontal motion as independent of vertical motion; they had to be treated together, as a whole.

b. [4] Galileo tested his assertions about motion by performing experiments. What was the main difficulty he faced in this process.

Answer: The main difficulty was accurately measuring short time intervals. Bodies falling naturally under gravity, for example balls being dropped off of the Leaning Tower of Pisa, have travel times of a few seconds at the most. To test this accurately would require time measurements much more sensitive than a second, something beyond the capability of Renaissance clocks.
c. [8] Describe briefly one of Galileo's experiments on motion that we discussed in class. Explain how this experiment was designed to get around the problem outlined in part a) of this question.

Answer: We discussed three experiments in class. Describing any one of these is sufficient to get credit for this part.

i. Rolling a ball (or sliding a block) down an incline. This got around the problem of measuring short time intervals by decreasing the acceleration of the object as it moved.

ii. Rolling/sliding a ball down an incline and then allowing it to jump off a ramp. By comparing two different measurements of the distance the ball travels in the horizontal direction ($d$) for ramps of two different heights ($h$), the need to measure time was eliminated from this experiment.

iii. The period of oscillation of a pendulum is independent of its mass.
PROBLEM 4 [20 pts]
a. [7] What was one of the big questions about motion post-Galileo, but pre-Newton. What process did people study to understand this question. Why did they choose to study this process and what new principle came out of that study?
Answer: The big question about motion that many people were trying to understand after Galileo’s death was how motion is transferred between objects.
This was most easily studied using collisions because collisions:
1. are fairly simple events with a clear “before” and “after” (at least all the complicated interactions happen in a short time period, the details of which can be ignored)
2. are reproducible (that is if you collide two objects in the same way, they will always behave identically)
Note: you only have to mention one of the two points above to get credit for this part of the questions.
The new principle that came out of this study was conservation of momentum. (You will only get partial credit if you say “conservation of energy/vis-viva here, since this is not universally true in collisions.)

b. [9] Describe each of Newton’s three laws of motion in words. (You can also use formulas if you’d like – but discuss what the symbols in them mean.)
Answer: The three laws are described below.
   i. 1st Law: The Law of Inertia
      This law says that if there is no net force on an object then its acceleration will be 0 (its velocity will not change).
   ii. 2nd Law: \( F = m a \)
      This law says that the only way to get an object to accelerate (change its velocity) is to apply force to the object. There are a few other points worth mentioning in regards to this law. However, you don’t need to include them in your answer to get full credit.
      a) The force in this law is the net force acting on the object. Since forces are simple vectors, they can be added together regardless of their origin.
      b) This law also says that the relationship between force and acceleration is simply mass. In this sense it is a definition of the term mass.
   iii. 3rd Law: Action and Reaction
      This law says that if two bodies exert forces on one another then the force of body 1 or body 2 (\( F_{12} \)) is equal and opposite of the force of body 2 on body 1 (\( F_{21} \))

c. [4] Newton’s 2nd Law is a statement of cause and effect. In this law, what is the cause and what is the effect?
Answer: Force is the cause and acceleration is the effect.
PROBLEM 5 [25 pts]

a. [8] Contrast the Aristotelian and Newtonian views of a rock falling to the ground. For each of the two cases discuss:
   i. what causes the rock to fall
   ii. how the motion would be affected if the rock were twice as heavy.

Answer:
Aristotle: The rock falls because it contains a large amount of the element “earth”, which seeks its “natural place”, which is at the center of the earth. A heavier rock would contain more earth and would therefore fall faster than a lighter rock.

Newton: Newton’s view of the motion of the rock is less philosophically neat than Aristotle’s. Newton claims that the rock falls because an external force (gravity) acts upon it, causing its motion to change. If gravity is the only external force acting on the rock (neglecting air resistance) then all rocks will fall with the same acceleration \( g = 9.8 \, \text{m/s}^2 \) regardless of how heavy they are.

b. [8] Contrast the Aristotelian and Newtonian views of an arrow flying through the air (after it leaves the bow). For each of the two cases discuss:
   i. whether it is sensible to discuss the horizontal and vertical motions of the arrow separately
   ii. why the arrow continues to fly after it leaves the bow

Answer:
Aristotle: In Aristotle’s view, it is not sensible to divide motion into horizontal and vertical components which behave independently. It is the total motion of the arrow through the air that matters. The fact that an arrow continues to fly after it leaves the bow was a real problem for Aristotelians. Since violent (horizontal) motion requires an agent to cause it, the arrow’s horizontal motion should cease as soon as the arrow ceases to be affected by the bowstring. At that point natural motion should take over and the arrow should fall straight to the ground. Various ideas were advanced to explain the continued flight of the arrow. For example, that air rushed in to fill the vacuum left behind the flying arrow and it was that air that pushed the arrow forward. However, none of these ideas were very satisfying.

Newton: Newton’s description of a flying arrow was much simpler. Two external forces cause the observed behavior after the arrow leaves the bow: gravity (which acts vertically) and air resistance (which has both vertical and horizontal components). By the Principle of Superposition the vertical and horizontal influences on the arrow can be considered independently. The arrow continues to fly (and not just fall) after it leaves the bow because, in the absence of air resistance, there is no horizontal force to change its initial horizontal motion. Even in the presence of air resistance, it takes a while for the arrow’s initial horizontal velocity to be changed to zero.
c.  [9] Draw a free body diagram showing all the forces (and their directions) acting on the arrow at some point in its flight (after it leaves the bow). Include air resistance and also indicate the direction of motion of the arrow. Describe (in words) the relative directions of the arrow’s velocity vector and the air resistance vector.

Answer: See the diagram below. In this diagram the air resistance vector points directly opposite to the velocity vector (the arrow’s direction of motion).