General Physics 1–Honors (PHYS 101H): Midterm 1–Solutions

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Overview and instructions

In this midterm you will apply your understanding of kinematics, and your knowledge of Newton's laws of motion, to problems in one and two dimensions.

Read the following instructions carefully.

There are **five questions**, for a total of **100 points**. **Attempt all questions**. The exam will finish at 11:45 am. Please write your name **on every sheet of paper you submit**. It is helpful if you include page numbers at the bottom of each page, too.

You may use:

- an electronic calculator;
- your own formula sheet, written or printed on one side of letter paper.

You may **not** use:

- electronic devices (except a calculator), including phones, tablets and laptops (unless previously arranged);
- textbooks or other reference resources;
- course notes or slides.

The first three questions are multiple choice. Your answer to these multiple choice questions should be written out and submitted as part of the rest of your solutions. For example, you could write, "Problem 1: my answer is **(a)**." Do **not** circle the options on the exam itself; I will not collect the exams and you will not receive credit for your answer.

The remaining questions require written solutions. You should show all your working and include important intermediate steps, equations, and results. You can receive partial credit for these problems, even if you don't complete the problem or provide a correct final answer. Please ensure that you highlight or emphasise your final answer (for example, by circling or underlining the final answer).

You are responsible for ensuring your solutions are legible. Present your solutions legibly and as logically as you can. What this means in practice is the following:

1. Write down what quantities you know.
2. Write down the relevant equations.
3. When carrying out manipulations or substituting values into equations, try to write each equality on separate lines or otherwise distinguish them clearly.
4. Circle or underline your final answers to identify them clearly.

Some hints for tackling problems in general:

1. Only substitute values at the end of your calculation and try to carry out all manipulations symbolically.
2. Double check the order of magnitude of your answer.
3. Double check the units of your answer.
4. Double check the number of significant figures of your answer. Remember that I am only looking for approximately the correct number of significant digits. If quantities are given to two or three significant digits, quote your answer to two or three (not one or five). Similarly if quantities are given to eight significant digits, do not quote your answer to two.

You do not have to tackle the questions in order. Briefly read through them all and then start on one!

Short questions

Remember, your answer to these multiple choice questions should be written out and submitted as part of the rest of your solutions.

Question 1 **10pts**

Quantum mechanics tells us that particles can behave like waves and waves can behave like particles. We know that waves are characterised by their wavelength and frequency. But what is the wavelength of a quantum particle? It turns out that there are two different ways to define the wavelength of a particle and they are called the **de Broglie wavelength** and the **Compton wavelength**. The de Broglie wavelength is the distance at which the wavelike nature of particles appears and the Compton wavelength, which is shorter than the de Broglie wavelength, is the distance at which the concept of a single particle breaks down completely. In addition to depending on Planck's constant, $h = 6.63 \times 10^{-34}$ kg m^2/s, the de Broglie wavelength depends on the particle momentum, p (with units kg m/s) and the Compton wavelength depends on the mass of the particle, m, and the speed of light, $c = 3.0 \times 10^8$ m/s. Which of the following pairs gives the correct expressions for the de Broglie and Compton wavelengths, respectively?

(a) hp, $\frac{hm}{c}$. (b) $\frac{h}{p}$, $\frac{hm}{c}$. (c) hp, $\frac{h}{mc}$. (d) $\frac{h}{p}$, $\frac{h}{mc}$.

Solution 1

The answer is (d).

Question 2 **10pts**

A person initially at Point P, illustrated in the Figure in the upper part of Figure 1, stays there for a moment and then moves along the axis to point Q and stays there a moment. She then runs quickly to R, stays there a moment, and the strolls slowly back to Q. Which of the position vs. time graphs in the lower part of Figure 1 correctly represents this motion?

(a) Graph (a)
(b) Graph (b)
(c) Graph (c)
(d) Graph (d)

Solution 2

The answer is (b). When the person is stationary, the position vs. time graph is flat. Point P is furthest from the (arbitrary) origin, so must take the largest value on the position axis in the graphs. When the person moves, the graph will have a constant slope, which is steeper when she moves quickly and less steep when she "strolls". The position never reaches zero, so the graph never reaches (and definitely doesn't cross) the horizontal time axes (which marks position equal to zero).

Question 3 **10pts**

Consider a person standing in an elevator that is accelerating upward. What is the relationship between the upward normal force exerted by the elevator floor on the person and the weight of

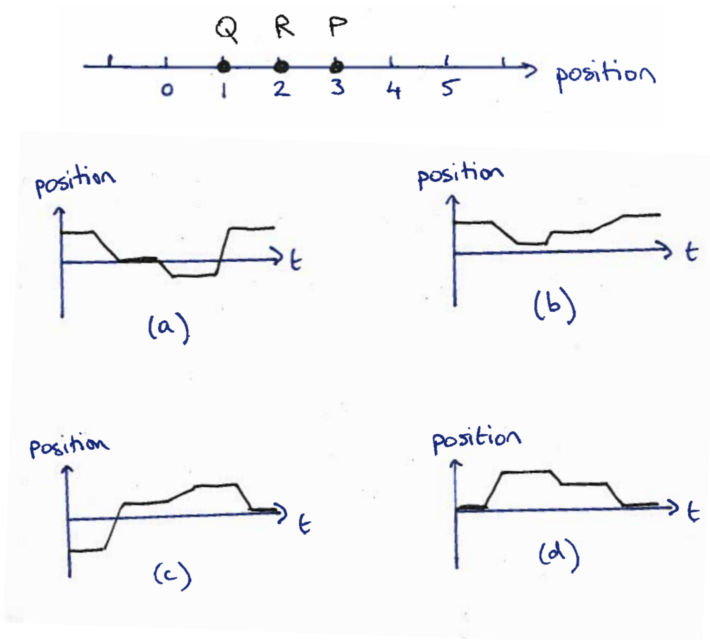

Figure 1: Diagram for Question 2.

the person?

(a) The normal force is smaller than the weight.
(b) The normal force is equal to the weight.
(c) The normal force is larger than the weight.

Solution 3

The answer is (c). The person accelerates upwards, so there must be a net force acting upwards. Thus the normal force acting on the person must be greater than their weight.

Longer questions

Remember, present your solutions legibly and as logically as you can. Highlight your final answer by underlining or circling it.

Question 4 — 30pts

Two blocks are connected over a massless, frictionless pulley, as shown in Figure 2. Block 2 lies on the slope and has mass $m_2 = 10.0$ kg. The coefficient of kinetic friction between block 2 and the incline is $\mu_K = 0.20$ and the angle of the incline is $\theta = 30°$.

If block 2 accelerates up the incline with an acceleration of magnitude $a = 2.2$ m/s^2, what is the mass of block 1?

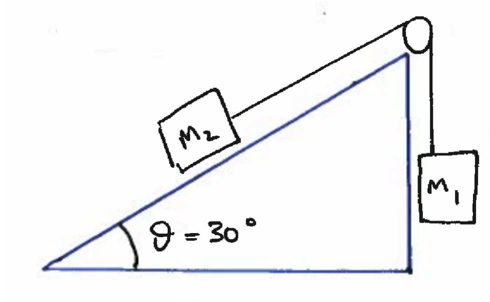

Figure 2: Diagram for Question 4.

Solution 4

The free-body diagrams for each block are shown in Figure 3. For block 2, I will choose a reference frame that is oriented perpendicular and parallel to the slope, with the positive direction pointing up the incline. For block 1, I define the positive direction as downwards.

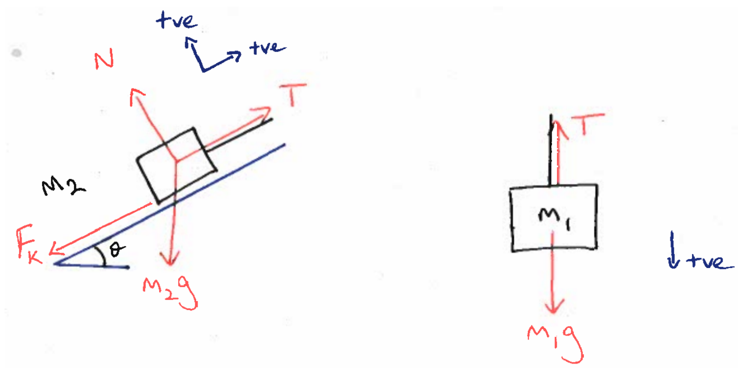

Figure 3: Free-body diagrams for Question 4.

Applying Newton's second law to block 1 gives

$$m_1 g - T = m_1 a,$$

where $a = 2.2$ m/s^2, as given in the question. This can be re-expressed as

$$T = m_1(g - a).$$

We don't know the tension, so we need to apply Newton's second law to block 2, as well. In the direction perpendicular to the slope, this gives

$$N - m_2 g \cos\theta = 0,$$

or

$$N = m_2 g \cos\theta.$$

Applying Newton's second law to the parallel direction gives

$$T - F_K - m_2 g \sin\theta = m_2 a,$$

which we can rearrange as

$$T = m_2 a + F_K + m_2 g \sin\theta.$$

We can now set this equal to our expression from block 1 to find

$$m_1(g - a) = m_2 a + F_K + m_2 g \sin\theta,$$

or

$$m_1 = \frac{m_2 a + F_K + m_2 g \sin\theta}{g - a}.$$

At this point, we have almost all the ingredients we need. The one extra factor we need is the relationship between the kinetic friction and the normal force,

$$F_K = \mu_K N = \mu_K m_2 g \cos\theta.$$

Now we can find the mass of block 1

$$\begin{aligned} m_1 &= \frac{m_2 a + \mu_K m_2 g \cos\theta + m_2 g \sin\theta}{g - a} \\ &= \frac{10.0(2.2 + 0.2 \cdot 9.81 \cdot \cos 30^\circ + 9.81 \cdot \sin 30^\circ)}{9.81 - 2.2} \\ &= \boxed{11.6\,\text{kg}}. \end{aligned}$$

Question 5 **40pts**

A ball, of mass 20 g, on a string of length 30 cm, is rotated in a horizontal circle at a height of 1 m, as shown in Figure 4. Find:

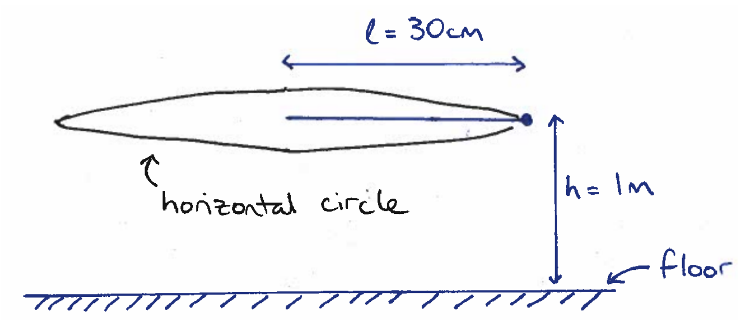

Figure 4: Diagram for Question 5.

(a) The force required to keep the ball moving at a speed of $v = 3.0$ m/s; and

(b) The horizontal distance travelled by the ball before it hits the ground, after being released by the person holding the string. Neglect air resistance.

Solution 5

(a) The centripetal force is given by

$$\begin{aligned} F_c &= \frac{mv^2}{r} \\ &= \frac{0.02 \cdot 3.0^2}{0.30} \\ &= \boxed{0.6\,\mathrm{N}} \end{aligned}$$

(b) When released the ball will travel in a straight line with initial velocity $v_0 = 3$ m/s. It will undergo parabolic motion from its initial height of $h = 1$ m, under the constant acceleration $a = -g$, due to gravity. This is illustrated in Figure 5. In the vertical direction, the

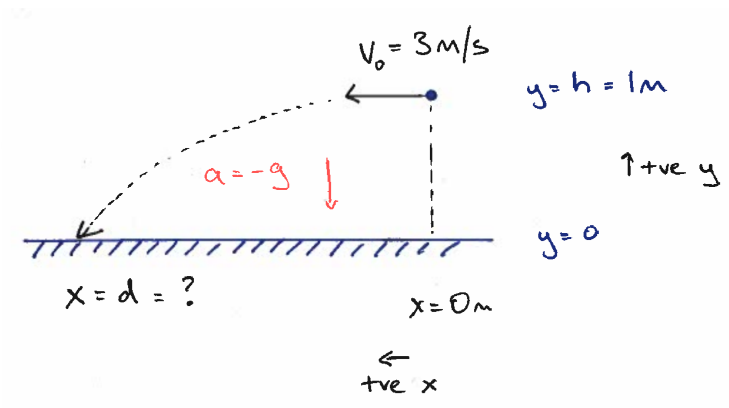

Figure 5: Kinematic diagram for Question 5.

kinematic equation is

$$0 = -\frac{gt^2}{2} + 0 \cdot t + h,$$

where the final y-position is the floor (that is, $y = 0$). Rearranging this gives

$$t = \sqrt{\frac{2h}{g}}.$$

In the horizontal direction, the kinematic equation is

$$d = v_0 t + 0.$$

Plugging in our expression for the time taken, t, gives

$$\begin{aligned} d &= v_0 t \\ &= v_0 \cdot \sqrt{\frac{2h}{g}} \\ &= 3.0 \cdot \sqrt{\frac{2 \cdot 1.0}{9.81}} \\ &= \boxed{1.4\,\mathrm{m}}. \end{aligned}$$