Phys 100
Fall 2023

Concepts of Physics: Final Exam

13 December 2023

Name: _____ **Total:** /100

Instructions

- There are 27 questions on 14 pages.
- Show your reasoning and calculations and always explain your answers.

Physical constants and useful formulae

$$\text{speed} = \frac{\text{distance traveled}}{\text{time elapsed}} \qquad s = \frac{d}{t}$$

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time elapsed}} \qquad a = \frac{v}{t}$$

$$\text{distance} = \frac{1}{2} \times \text{acceleration} \times \text{time}^2 \qquad d = \frac{1}{2} \times a \times t^2$$

$$\text{final speed} = \text{initial speed} + \text{acceleration} \times \text{time} \qquad v_f = v_i + a \times t$$

$$\text{acceleration} = \frac{\text{net force}}{\text{mass}} \qquad a = \frac{F}{m}$$

$$\text{earth's gravitational force} = \text{mass} \times 9.8 \qquad F_{\text{grav earth}} = m \times 9.8$$

$$\text{gravitational force} = 6.67 \times 10^{-11} \times \frac{\text{mass}_1 \times \text{mass}_2}{\text{distance}^2} \qquad F_{\text{grav}} = 6.67 \times 10^{-11} \times \frac{m_1 \times m_2}{d^2}$$

$$\text{KE} = \frac{1}{2} \times \text{mass} \times (\text{speed})^2 \qquad KE = \frac{1}{2} m \times v^2$$

$$\text{speed} = \sqrt{2 \times \text{KE}/\text{mass}} \qquad v = \sqrt{\frac{2 \times KE}{m}}$$

$$\text{gravPE} = \text{mass} \times 9.8 \times \text{height} \qquad PE = m \times 9.8 \times h$$

$$\text{height} = \frac{\text{gravPE}}{\text{mass} \times 9.8} \qquad h = \frac{PE}{m \times 9.8}$$

Physical constants and useful formulae

$$\text{power} = \frac{\text{energy gain}}{\text{time elapsed}} \qquad P = \frac{E}{t}$$

$$\text{energy} = \text{power} \times \text{time elapsed} \qquad E = P \times t$$

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \qquad \varepsilon = \frac{E_{\text{output}}}{E_{\text{input}}}$$

$$\text{useful energy output} = \text{efficiency} \times \text{energy input} \qquad E_{\text{output}} = \varepsilon \times E_{\text{input}}$$

$$\text{energy input} = \frac{E_{\text{output}}}{\text{efficiency}} \qquad E_{\text{input}} = \frac{E_{\text{output}}}{\varepsilon}$$

$$\text{electron charge} = -1.6 \times 10^{-19}\,\text{C} \qquad \text{proton charge} = +1.6 \times 10^{-19}\,\text{C}$$

$$\text{current} = \frac{\text{charge}}{\text{time}} \qquad I = \frac{Q}{T}$$

$$\text{charge} = \text{current} \times \text{time} \qquad Q = I \times T$$

$$\text{frequency} = \frac{1}{\text{time per cycle}} \qquad f = \frac{1}{T}$$

$$\text{wave speed} = \text{wavelength} \times \text{frequency} \qquad s = \lambda \times f$$

$$\text{frequency} = \frac{\text{wave speed}}{\text{wavelength}} \qquad f = \frac{s}{\lambda}$$

$$\text{wavelength} = \frac{\text{wave speed}}{\text{frequency}} \qquad \lambda = \frac{s}{f}$$

$$\text{speed of light} = 3.0 \times 10^{8}\,\text{m/s} \qquad c = 3.0 \times 10^{8}\,\text{m/s}$$

$$\text{photon energy} = 6.63 \times 10^{-34}\,\text{Js} \times \text{frequency} \qquad E_{\text{photon}} = 6.63 \times 10^{-34}\,\text{Js} \times f$$

$$\text{frequency} = \frac{\text{photon energy}}{6.63 \times 10^{-34}\,\text{Js}} \qquad f = \frac{E_{\text{photon}}}{6.63 \times 10^{-34}\,\text{Js}}$$

$$\text{number of photons} = \frac{\text{total energy}}{\text{photon energy}} \qquad N = \frac{E}{E_{\text{photon}}}$$

$$\text{total energy} = \text{number of photons} \times \text{photon energy} \qquad E = N \times E_{\text{photon}}$$

$$\text{width central region} = \frac{2 \times \text{wavelength}}{\text{slit width}} \times \text{screen distance} \qquad w = \frac{2\lambda}{a}\,d$$

$$\text{particle wavelength} = \frac{6.63 \times 10^{-34}\,\text{Js}}{\text{mass} \times \text{speed}} \qquad \lambda = \frac{6.63 \times 10^{-34}\,\text{Js}}{m \times v}$$

Question 1

When the position of any plant in the solar system is observed from Earth against the background stars, that planet will appear to undergo retrograde motion for some periods.

a) Describe what retrograde motion is and how it differs from ordinary motion.

b) Consider a simple geocentric model of the solar system, where each planet orbits in a perfect circle around Earth. Does this model predict that there will be periods of retrograde motion? Explain your answer with a diagram.

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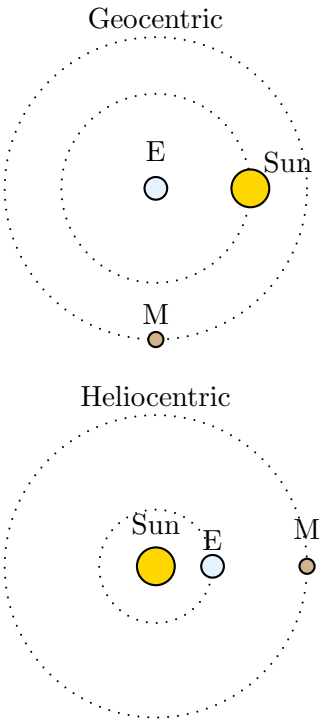
Question 2

Consider the following two models of the planet Mercury in the solar system:

- Geocentric model where Sun and Mercury orbit the Earth at different rates,
- Heliocentric model where Earth and Mercury orbit the Sun at different rates.

The rate refers to the time taken to complete one orbit.
For *each* model, does the model predict that the apparent size (size as viewed from Earth) of Mars as viewed from Earth will stay the same or vary throughout Mars' motion? Explain your answer.



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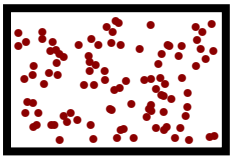
Question 3

A container is filled with a gas. At one instant the left wall of the container is pushed inwards. This is done so that the temperature of the gas and the number of gas molecules remain constant. Consider the pressure of the gas within the container after the wall has been pushed inwards in comparison to before. Which of the following (choose one) is true?



i) The pressure after is the same (as before) since the temperature is the same.
ii) The pressure after is the same since the strength of the collisions of the molecules is the same as before.
iii) The pressure after is larger since the molecules collide with each other more often.
iv) The pressure after is larger since the molecules collide with each the walls more often.
v) The pressure after is smaller since the molecules have less room to move.

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Question 4

One ethane molecule has mass of about 5×10^{-26}kg. A small sample of pure ethane has mass 15×10^{-6}kg. Which of the following (choose one) is the number of molecules in the sample?

i) 75×10^{-32}
ii) 3.3×10^{-21}
iii) 3×10^{20}
iv) 3×10^{32}
v) 75×10^{32}

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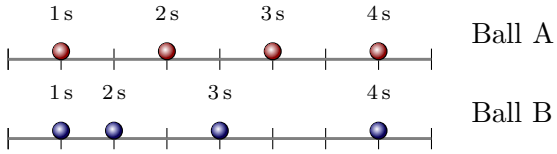
Question 5

Two balls slide along horizontal surfaces. The positions of the balls are recorded at intervals spaced 1 s apart. Tick marks on the axes are exactly 1 m apart.



a) Determine the average speed of each ball in the interval from 1s to 2s.

b) Which of the following (choose one) is true regarding the acceleration of the balls during the interval from 0 s to 2 s?

i) Both balls have acceleration 0 m/s^2.
ii) Both balls have acceleration 2 m/s^2.
iii) Ball A has acceleration 0 m/s^2 and ball B has non-zero acceleration.
iv) Ball B has acceleration 0 m/s^2 and ball A has non-zero acceleration.

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Question 6

At one instant a mouse moves with speed 5.0 m/s to the right. For the next 4.0 s, the mouse has acceleration 1.5 m/s^2. Determine the speed of the mouse at the end of this period.

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Question 7

A 5.0kg box is pushed across a horizontal floor. It travels in a straight line with constant speed 6.0m/s. Which of the following (choose one) is the **net force** acting on the box?

i) 0.0N
ii) 5.0N
iii) 6.0N
iv) 30.0N

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Question 8

Two rockets travel in straight lines. At one instant rocket A (mass 500 kg) travels with speed 20 m/s and at the same instant rocket B (mass 200 kg) travels with speed 10 m/s. In the next minute, rocket A's engines exert a constant force of 1000 N (on rocket A) and rocket B's engines exert a constant force of 1000 N (on rocket B). During the period when their engines are operating, which rocket has the greater acceleration? Explain your answer.

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Question 9

A person lifts a coffee cup vertically and, for a while it moves up with constant speed. Which of the following (choose one) is true *while the coffee mug moves up with constant speed?*

i) The force exerted by the person on the cup is the same as the gravitational force exerted by Earth on the cup.
ii) The force exerted by the person on the cup is smaller than the gravitational force exerted by Earth on the cup.
iii) The force exerted by the person on the cup is larger than the gravitational force exerted by Earth on the cup.

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Question 10

An aircraft flies in a straight line at a constant speed of 180 m/s. Near to the ground a breeze blows a small leaf, which speeds up for a few seconds. During this time, which of the following (choose one) is true?

i) The *net* force on the aircraft is the same as the *net* force on the leaf.
ii) The *net* force on the aircraft is larger than the *net* force on the leaf.
iii) The *net* force on the aircraft is smaller than the *net* force on the leaf.

Briefly explain your answer.

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Question 11

Consider the moon orbiting Earth. The Earth exerts a gravitational force on the moon. Which of the following is true?

i) The moon does *not* exert a gravitational force on the Earth.
ii) The moon does exert a gravitational force on the Earth and this has the same size as the force exerted by the Earth on the moon.
iii) The moon does exert a gravitational force on the Earth and this is larger than the force exerted by the Earth on the moon.
iv) The moon does exert a gravitational force on the Earth and this is smaller than the force exerted by the Earth on the moon.

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Question 12

A 2.0 kg wooden ball moves with speed 4 m/s. A 8.0 kg block of metal moves with speed 2m/s. Which of the following (choose one) is correct?

i) The kinetic energy of the ball is smaller than the kinetic energy of the block.
ii) The kinetic energy of the ball is larger than the kinetic energy of the block.
iii) The kinetic energy of the ball is the same as the kinetic energy of the block.
iv) Whether the kinetic energy of the ball is larger than that of the block depends on their gravitational potential energies.

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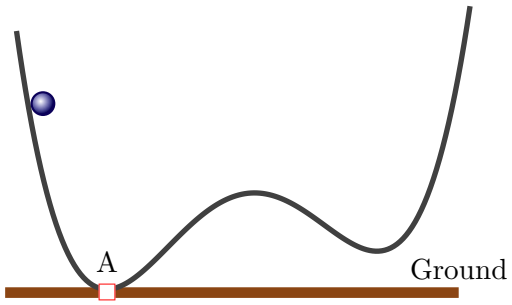
Question 13

A 0.40 kg ball is released from rest at the illustrated the point on a track. The ball slides down the frictionless track without any air resistance. It reaches point A, at the ground level with speed 10 m/s.



a) Determine the total energy of the ball at point A.

b) Determine how high (above the ground) the ball ascends on the right side of the track.

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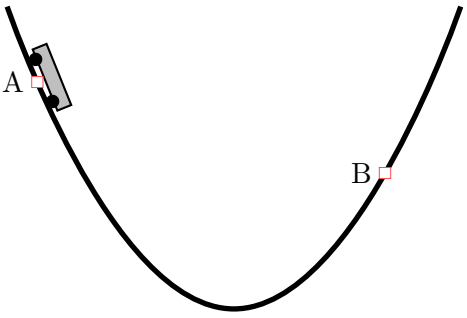
Question 14

A cart is released from rest at the point A on the illustrated track. The cart slides down the left side of the track and only ascends as far as B on the right side before sliding back down again. Someone calculates the total mechanical energy, using

$$E = KE + PE.$$



Is this energy conserved as the cart moves from A to B? Explain your answer.

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Question 15

A solar panel receives 800 J of energy from the Sun per second. The panel converts this into electric energy with efficiency 0.60. Determine the electrical energy that it produces each second.

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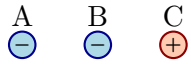
Question 16

Three charged particles are located as illustrated. The distances between adjacent charges are the same and the sizes of their charges are the same. Charges B and C are held fixed. Charge A is initially held at rest and is then released. After it is released, which of the following (choose one) will it do?



i) Remain at rest.
ii) Move left.
iii) Move right.

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Question 17

Ordinary table salt consists of a collection of sodium and chlorine ions. Each sodium ion is formed from a neutral sodium atom by losing one electron. Each chlorine ion is formed from a neutral chlorine atom by gaining one electron. Is it possible to have a piece of neutral table salt that contains *more* sodium ions than chlorine ions? Explain your answer.

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Question 18

Lithium is a light metal. There are several types of lithium atom but each has 3 protons. The most common type has 4 neutrons and a single such atom has mass 1.16×10^{-26} kg.

a) How many electrons are there in a single neutral lithium atom? Explain your answer.

b) Suppose that you cut a 0.0010 kg piece of lithium. Show that there are approximately 8.6×10^{22} atoms in this piece of lithium.

c) Determine the total charge of *the entire collection of the electrons* in a 0.0010 kg piece of lithium.

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Question 19

An AM radio station transmits an electromagnetic wave with frequency 8.0×10^5 Hz. An FM radio station also transmits an electromagnetic wave, but with frequency 9.0×10^7 Hz. Which of the following (choose one) is true?

i) The AM radio wavelength is larger than the FM radio wavelength.
ii) The AM radio wavelength is smaller than the FM radio wavelength.
iii) The AM radio wavelength is the same size as the FM radio wavelength.
iv) The sizes of the wavelengths depend on the distance from the radio transmitters.

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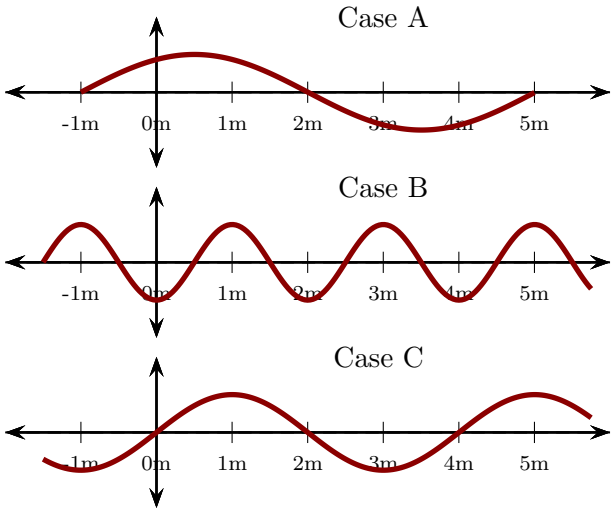
Question 20

Various waves on strings are as illustrated.

a) Rank the waves in order of increasing wavelength. Indicate equality whenever it occurs. Explain your answer.



b) Rank the waves in order of increasing frequency. Indicate equality whenever it occurs. Explain your answer.

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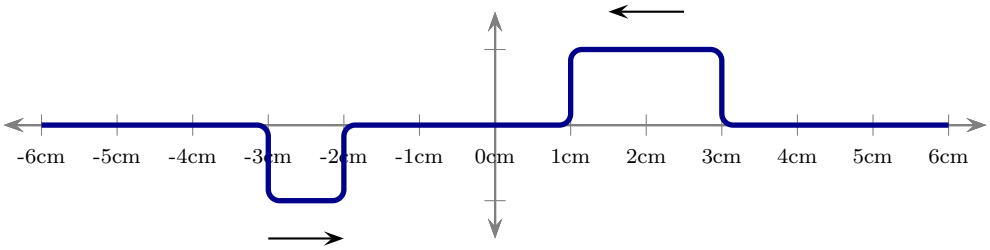
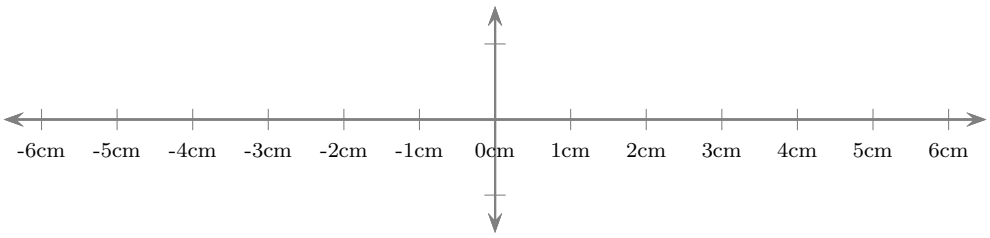
Question 21

Two rectangular wave pulses move along a string with speeds 1 cm/s. Initially the string appears as illustrated.



Sketch the appearance of the string 2 s after the initial instant, using the axes below.



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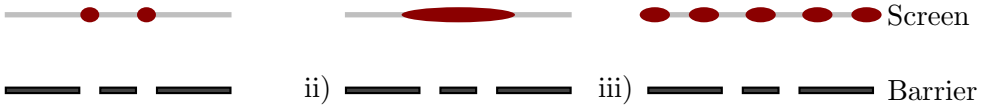
Question 22

Light (of one wavelength or color) travels toward a barrier containing two narrow slits. A screen is placed beyond the barrier. The light beam arriving at the barrier is wide enough to cover both slits. In the diagrams below light passes from the bottom to the top of the diagram. Which of the following (choose one) best represents pattern produced by the light on the screen?



Briefly explain why the pattern that you selected occurs.

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Question 23

Various light bulbs each produce light of exactly one frequency (color), but the value of the frequency varies from one bulb to another. They all produce exactly the same total energy per second. Which of the following (choose one) is true?

i) Each photon produced by one of these bulbs has the same energy as each photon produced by any other bulb.
ii) The larger the frequency of the light, the more energy each photon has.
iii) The larger the frequency of the light, the less energy each photon has.
iv) The larger the frequency of the light, the more photons it produces per hour.

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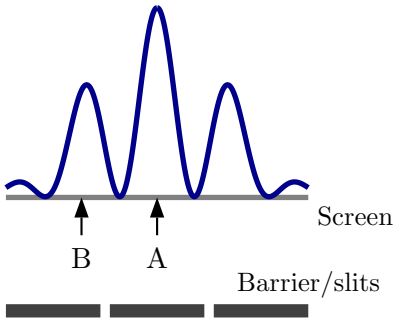
Question 24

Light with one frequency travels toward an arrangement of barriers and slits as illustrated. The intensity profile of the light on the screen is as illustrated. Two points are marked on the screen. After a very short interval it is observed that 1000 photons arrive at the point A. Which of the following (choose one) is true during the same short interval?



i) No photons could have arrived at B.
ii) About 100 photons arrived at B.
iii) About 600 photons arrived at B.
iv) About 1000 photons arrived at B.

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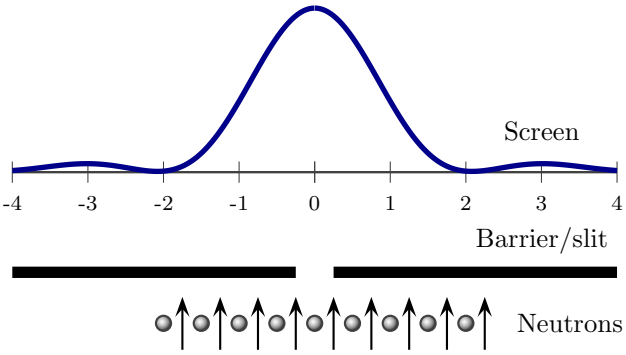
Question 25

Neutrons are fired, one at a time, toward a narrow slit. They are all fired toward the slit in precisely the same way. The probability distribution for arrival on a screen is illustrated. Which of the following (choose one) is most accurate?



i) **All** neutrons that pass through the slit will arrive at the same location on the screen since they were fired toward the slit in the same way.

ii) **All** neutrons that pass through the slit will arrive between -2 and 2 on the screen.

iii) **Most** neutrons that pass through the slit will arrive between -2 and 2 on the screen.

iv) **Any single** neutron that passes through the slit will arrive simultaneously at many locations on the screen.

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Question 26

Describe an experiment that has been done that shows that particles sometimes need to be described in terms of waves. Your description should include:

- A simplified description of the basic steps in the experiment.
- A simple description of what occurs (the outcome of the experiment) when the experiment is done.
- A brief description of why a wave model of matter can help to describe the outcome of the experiment.

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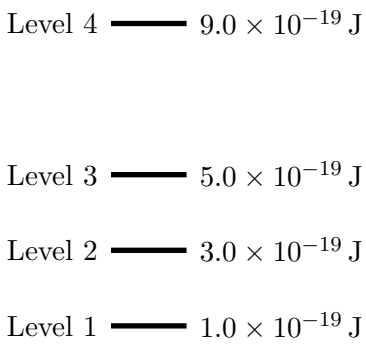
Question 27

An artificial atom has four energy levels as illustrated.



a) Determine all possible energies of photons that the atom could emit.

b) Determine all possible frequencies of electromagnetic radiation that the atom could emit.

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