University of São Paulo

São Carlos Institute of Physics

Graduate Program

Admission Test

Biomolecular Physics

Second Semester 2024

Exam Booklet

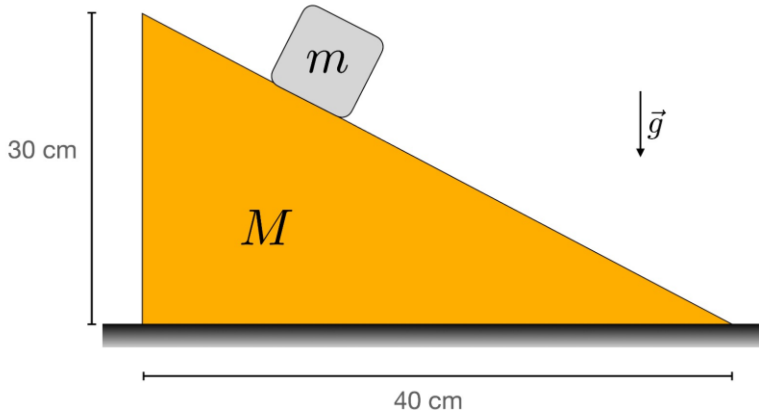
Candidate's Code:

Physics Questions
(Multiple Choice)

Instructions: The Physics questions are multiple-choice. For these questions, please indicate your chosen answer directly in this exam booklet by marking the corresponding square with an "X" using a black or blue pen. Do not use this exam booklet for elaborating on your answers or as a draft. You may use the provided Notepaper for developing your answers or as a draft paper. **The answers considered for correction will be the ones marked in the exam booklet.**

Question 1:

A block of mass $m = 1kg$ slides without friction on a wedge of mass M, whose dimensions are represented in the figure. There is friction between the wedge and the surface on which it rests, and the coefficient of static friction is $\mu = 1/10$. What is the smallest value of M (in kg) such that the block slides without the wedge slipping to the left in the figure? If necessary, *use* $g = 10 m/s^2$.



Place an 'X' in the square that corresponds to the correct answer.

☐ 114/35

☐ 4/3

☒ 104/25

☐ 24/5

☐ None of the proposed answers.

Answer:

The block of mass *m = 1kg*, while sliding, exerts a normal force on the inclined surface of the wedge, which is given by (see figure below):

$N = \mu g \cos(\theta)$.

We know $\cos(\theta) = 4/5$, as the wedge has the shape of a 3-4-5 right triangle. Thus, the wedge experiences a horizontal force to the left, represented in the figure, of magnitude

$N_h = m g \cos(\theta) \sin(\theta)$

and another vertical force downward given by

$N_v = m g \cos^2(\theta)$.

The maximum static friction force is then given by

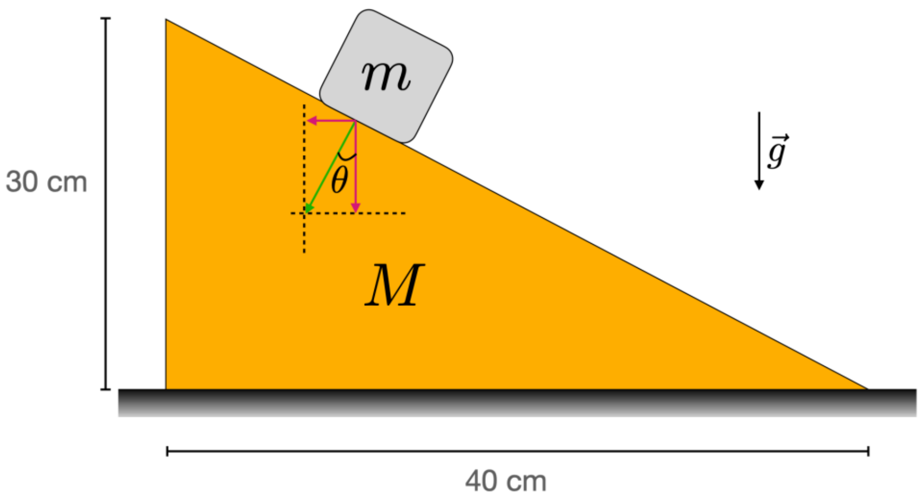
$F_{max} = \mu g [M + m \cos^2(\theta)]$,

since the normal reaction to the supporting plane is given by the weight of the wedge, Mg, added to the vertical component of the force exerted by the block on the wedge. In the situation where the mass M is at the minimum such that the wedge does not slide, we are in the situation of maximum static friction, therefore

$N_h = F_{max}$

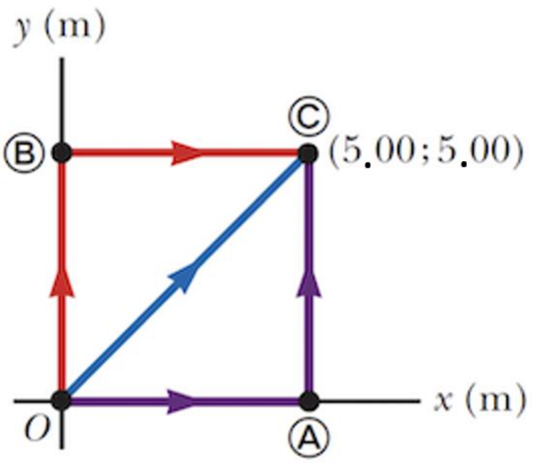
from which we obtain

$M_{min} = m \cos(\theta) (\sin(\theta)/\mu - \cos(\theta)) = 104/25$ kg.



Question 2:

A particle moves on the xy plane under the action of a force **F** = $2y\mathbf{i} + x^2\mathbf{j}$, with F given in Newtons and x and y in meters. The particle moves from the origin to its final position at x=5.00m and y=5.00m (point C in the figure) following three different paths: OAC, OC, and OBC. We denote the work done by the force on the particle along each of these paths by W(OAC), W(OC) e W(OBC). About the work done in each of the paths it is correct that:



Place an 'X' in the square that corresponds to the correct answer.

X W(OBC)<W(OC)<W(OAC)

☐ W(OBC)<W(OAC)<W(OC)

☐ W(OBC)=W(OAC)=W(OC)

☐ W(OC)<W(OAC)<W(OBC)

☐ None of the proposed answers.

Answer:

1. W(OAC) = 125 J since in OA the work is zero (force is perpendicular to the trajectory) while in OC one has **F.dl** = x^2dy, with x fixed at 5.00m, and, therefore

W(OAC) = $\int_0^5 x^2 dy = 125J$.

2. W(OC) = 66.7 J. In this case the trajectory is such that y=x, and dy=dx. Then, **F.dl** = 2x dx + x^2dx. One finds for the work done by the force:

W(OC) = $\int_0^5 2xdx + \int_0^5 x^2 dx = 66.7J$.

3. W(OBC) = 50 J since the work on the path OB is zero (force is perpendicular to the trajectory) while in BC one has **F.dl** =2ydx with y=5.00m and, therefore:

W(OBC) = $\int_0^5 2ydx = 50J$.

Hence, the correct answer is W(OBC)<W(OC)<W(OAC).

Question 3:

An object oscillates with angular frequency $\omega = 8.0$ rad/s. At $t = 0$ s, the object is at $x = 4.0$ cm with an initial velocity $v_x = -25$ cm/s. Find the amplitude, the phase constant, and x as a function of time.

Place an 'X' in the square that corresponds to the correct answer.

☒ 5.1 cm; 0.66 rad; $x = (5.1\text{ cm}) \cos[(8.0\text{ s}^{-1})\, t + 0.66]$

☐ 2.6 cm; 6.6 rad; $x = (2.6\text{ cm}) \cos[(4.0\text{ s}^{-1})\, t + 6.6]$

☐ 5.1 cm; 0.51 rad; $x = (5.1\text{ cm}) \cos[(4.0\text{ s}^{-1})\, t + 0.51]$

☐ 1.8 cm; 0.06 rad; $x = (18.0\text{ cm}) \cos[(8.0\text{ s}^{-1})\, t + 0.86]$

☐ None of the previous answers

Answer:

The initial position and velocity are related to the amplitude and phase constant.

$x = A\cos(\omega t + \delta)$ e $v_x = -\omega A\,\mathrm{sen}(\omega t + \delta)$

Thus,

$x_0 = A\cos(\delta)$

and

$v_{0x} = -\omega A\,\mathrm{sen}(\delta)$.

Therefore,

$v_{0x}/x_0 = -\omega A\mathrm{sen}(\delta)/A\cos(\delta) = -\omega\tan(\delta)$.

Consequently,

$\tan(\delta) = -v_{0x}/\omega_{x0}$

$\delta = \tan^{-1}(-v_{0x}/\omega_{x0}) = \tan^{-1}(-(-25\ \mathrm{cm/s})/(8.0\ \mathrm{rad/s})\ (4.0\ \mathrm{cm}))$
$= 0.66\ \mathrm{rad}$

$A = x_0/A\cos(\delta) = 4.0\ \mathrm{cm}/\cos(0.66) = 5.1\ \mathrm{cm}$

$x = (5.1\ \mathrm{cm})\cos[(8.0\ \mathrm{s}^{-1})t + 0.66]$

Question 4:

Consider the harmonic wave function on a string:

$Y(x,t) = (0.030\ \text{m})\ \text{sen}[(2.2\ \text{m}^{-1})\ x - (3.5\ \text{s}^{-1})\ t]$

Find the wavelength, period, and maximum speed of any point on the string.

Place an 'X' in the square that corresponds to the correct answer.

☐ 0.4 m; 1.7 s; 1.1 m/s

☐ 5.8 m; 0.9 s; 3.5 m/s

X 2.9 m; 1.8 s; 0.11 m/s

☐ 0.3 m; 2.2 s; 0.35 m/s

☐ None of the previous answers

Answer:

The wave travels in the +x direction.

$v = \lambda/T = \omega/k = 3.5\ s^{-1}/2.2\ m^{-1} = 1.6\ m/s$

$\lambda = 2\pi/k = 2\pi/2.2\ m^{-1} = 2.9\ m$

$T = 2\pi/\omega = 2\pi/3.5\ s^{-1} = 1.8\ s$

$f = 1/T = 1/1.8\ s = 0.56\ Hz$

$A = 0.030\ m$

$v_y = (0.030\ m)\ (-\ 3.5\ s^{-1})\ \cos[(2.2\ m^{-1})\ x - (3.5\ s^{-1})\ t]$

$= -\ (0.105\ m/s)\ \cos[(2.2\ m^{-1})\ x - (3.5\ s^{-1})\ t]$

$v_{y,max} = 0.11\ m/s$

Question 5:

A reservoir with a movable piston is in contact with a heated plate. Initially, this reservoir contained 1.00 kg of liquid water at 100°C, which was completely converted into vapor at 100°C by boiling at atmospheric pressure (1.01×10^5 Pa). The volume changed from 1.00×10^{-3} m^3 in the liquid state to 1.671 m^3 of water vapor only. Knowing that the heat of fusion for water is 333 kJ/kg and that of vaporization is 2260 kJ/kg, determine:

Determine W, the work done by the system during this process, Q, the amount of heat added in the process, and ΔU, the change of internal energy.

Place an 'X' in the square that corresponds to the correct answer.

☐ None of the proposed answers.

☒ W= 169 kJ; Q= 2260 kJ; ΔU= 2.09 MJ

☐ W= 68 kJ; Q= 2260 kJ; ΔU= 2.43 MJ

☐ W= 68 kJ; Q= 0 kJ; ΔU= 2.09 MJ

☐ W = 169 kJ; Q = 333 kJ; ΔU= 2.09 MJ

Answer:

1. As the pressure is constant during the boiling process, the work is calculated by the following equation, where the pressure can be placed outside the integral.

$$\mathrm{W} = -\int_{V_i}^{V_f} P\, dV = P\left(V_f - V_i\right) = 1.01 \cdot 10^5\ Pa \cdot (1.671\ m^3 - 1.00 \cdot 10^{-3}\ m^3) = 169\ kJ$$

2. As there is no change in temperature, but only a change in phase, we use the heat of transformation related to the vaporization process:

$$Q = L \cdot m = 2260 \frac{kJ}{1.00} kg = 2260\ kJ$$

3. The change in internal energy is obtained by the first Law of Thermodynamics:

$$Q = \Delta U + W \rightarrow \Delta U = Q - W$$
$$\Delta U = 2260\ kJ - 169\ kJ = 2.09\ MJ$$

This quantity is positive, as the internal energy of the system has increased. It is less than the value added in the system because approximately 169 kJ of added heat was transformed into external work against atmospheric pressure.

QUESTIONS ON BIOLOGICAL SCIENCE AND BIOCHEMISTRY
(Multiple Choice)

Instructions: The questions on biological science and biochemistry are multiple-choice. For these questions, please indicate your chosen answer directly in this exam booklet by marking the corresponding square with an "X" using a black or blue pen. Do not use this exam booklet for elaborating on your answers or as a draft. You may use the provided Notepaper for developing your answers or as a draft paper. **The answers considered for correction will be the ones marked in the exam booklet.**

Question 1:

Which one of the following statements better describe the function of operon lac in E. coli?

☐ It encodes enzymes that are involved in the glucose metabolism.

☒ It represses the synthesis of enzymes involved in lactose metabolism when the lactose is absent.

☐ It enhances the uptake of lactose from the environment.

☐ It prevents the protein synthesis when glucose is present.

☐ It is responsible for the replication of the bacterial genome.

Question 2:

Considering the structure and function of biological membranes, which of the following statements best describes the role of cholesterol in the plasma membrane of eukaryotic cells?

☐ They facilitate the active transport of ions across the membrane, reducing the need for ATP.

☐ They act mainly as source of energy in conditions of glucose deprivation.

☐ They promote the formation of permanent aqueous pores, increasing permeability to polar molecules.

☐ They serve as main components of channel proteins, facilitating passive diffusion.

☒ They increase membrane fluidity at low temperatures and stabilize the membrane at high temperatures

Question 3:

Regarding carbohydrates, it is correct to say that:

☐ They can exist in linear or cyclic form. Pyranoses, like glucose, are usually formed by the condensation reaction between the hydroxyl attached to the carbon 6 and the acetal group on carbon 1.

☐ When forming the glycosidic bond, a disaccharide always maintains a free anomeric carbon, therefore always having a reducing terminal

☐ Since the α and β anomers of D-glucose undergo interconversion in solution, the composition of a polysaccharide in terms of anomers is functionally irrelevant.

☒ Aldoses with six carbons can form furanosid rings (five-membered rings).

☐ None of the above alternatives.

Question 4:

Regarding the structure of DNA, it is correct to say that:

☐ Watson and Crick's model for the structure of DNA refers to one of three possible forms, the Z form with a shorter diameter (~18 Å) and 12 base pairs per helix turn.

☐ The variability in the structure of DNA comes from the torsional flexibility in the connection of the phosphodeoxyribose chain, the flexibility in the conformation of the deoxyribose itself, and the flexibility in the arrangement of the DNA strands, which can occur in a parallel or anti-parallel manner.

☒ Although there is evidence of the occurrence of DNA in the Z and B forms, the occurrence of the A form in cells is still uncertain.

☐ The planar arrangement of the bases (inclination < 20° in relation to the helix axis) is observed in all forms of DNA and is necessary for the formation of the hydrogen bond between the bases of complementary parallel strands.

☐ None of the above alternatives.

Questão 5:

In the context of enzymology, what does the Lineweaver-Burk plot represent?

☐ The rate of an enzymatic reaction as a function of substrate concentration.

☐ The change in enzymatic activity over time.

X The reciprocal relationship between enzyme velocity and substrate concentration in a reciprocal manner.

☐ The effect of temperature on enzymatic activity.

☐ The influence of pH on the structure and function of the enzyme