UNIVERSITY OF WATERLOO
DEPARTMENT OF PHYSICS

PHYSICS 112 – MIDTERM TEST – WINTER 2009

Saturday, FEBRUARY 28, 2009; 3:00 – 5:00 P.M.

Aids Permitted: Calculator

IMPORTANT INSTRUCTIONS – READ CAREFULLY TO AVOID PENALTY

1. Mark your answer sheet in dark lead PENCIL only. Avoid erasures by checking answers before marking them. Mark your ID Number and section in the space provided. Also (THIS IS IMPORTANT) fill in the correct ovals for your ID Number and section (e.g. 001). Do not mark "card number" column in the answer field. Your last answer should be in row 12.

   NOTE: KEEP COMPUTER SHEET FACE DOWN WHEN NOT IN USE

2. Print name, etc., in the upper right part of the computer sheet.

3. Use the space available on the test paper for your solutions (under the question, or back of previous page).

4. Check that this has 12 questions. All questions are of equal value, so don't get hung up and miss the easy ones.

5. There is no penalty marking for incorrect answers. Guess if you must! In fact please mark one answer for each question even if you must guess. (This saves a hand search for possible answers which have been marked too lightly.)

6. Ask a proctor to clarify a question if you think that is necessary.

7. Assume any data given are accurate to as many figures as needed. Ignore round off errors.

Good Luck!!!

1. A sound pipe with one closed end oscillates in its 5^{th} harmonic at 165 Hz. It is then made to oscillate in its 7^{th} harmonic at 231 Hz. Calculate the fundamental frequency. Answer in Hz.

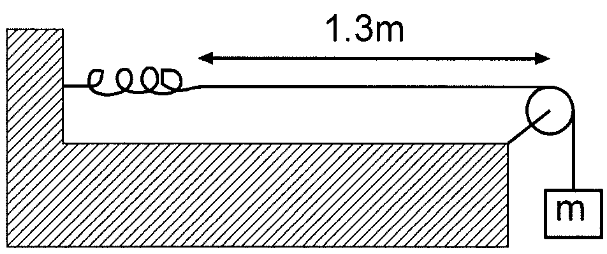
a) 15 b) 33 c) 44 d) 66 e) None of these

one closed end so $f_n = n f_1 \quad n = 1, 2, 3, \ldots$

$f_5 = 165\,Hz = 5 f_1$

$f_1 = \frac{165}{5} = 33\,Hz$

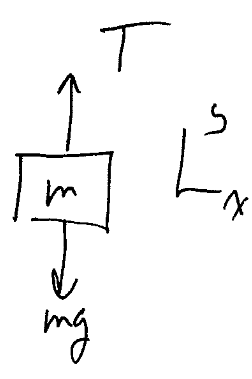
2. A freely hanging mass of 20kg is attached to a string which passes over a light pulley and is then attached to one end of a spring as shown in the figure. The other end of the spring is attached to the wall. The system shown is at rest in equilibrium. The horizontal portion of the string is 1.3 m long and has a mass of 110 g. Find the speed of a transverse pulse that is sent down the horizontal part of the string. You may ignore the mass of the vertically hanging string. Answer in m/s.



a) 2342 b) 19.6 c) 187.4 d) 48.1 e) None of these

$v = \sqrt{\frac{T}{\mu}}$

$\mu = \frac{m_{string}}{l_{string}} = \frac{0.11}{1.3}$



no acceleration so

$T = mg = 20 \cdot 9.81$

tension in string does not change because of spring!

So $v = \sqrt{\frac{20 \cdot 9.81}{0.11/1.3}}$

$= 48.1\,m/s$

3. Find the amount of work needed to bring in a 12μC charge form infinity to a point exactly in the middle of two charges, q_1=16μC and q_2=-16μC, which are separated by 0.9 m. Answer in J.

a) 7.68 b) -7.68 c) -3.84 d) 3.84 e) None of these

0.45m 0.45m

$q_1 = +16\mu C$ $V=0$ $q_2 = -16\mu C$

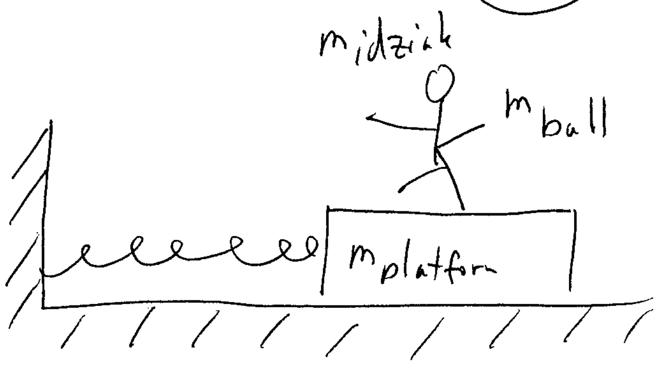
$$V_{middle} = \frac{kq_1}{r} + \frac{kq_2}{r}$$
$$= \frac{k}{r}(q_1+q_2) = \frac{k}{r}(+16\times10^{-6} - 16\times10^{-6})$$
$$= 0$$

$V_\infty = 0$ $V_\infty - V_0$

So $\Delta V = V_\infty - V_0 = 0$ so work $= 0$

4. Prof Idziak (m=120 kg) volunteers for an endurance test. He is made to stand on a platform (m=52 kg) while holding a 45 kg steel ball. The platform rests on a frictionless horizontal surface and is attached to a horizontal spring. The system is put into oscillation on the horizontal surface such that the maximum speed is 7.3 m/s. The spring constant is 490 N/m. While going through the equilibriuim position, Prof Idziak releases the ball and it falls on the ground. Find the new amplitude of the motion. Answer in m.

a) 2.25 b) 3.23 c) 4.32 d) 5.43 e) None of these



dropping the ball does not change the velocity of Prof Idziak and platform.
So after the ball has been dropped, have conservation of energy

So $U_{max} = K_{max}$ $\frac{1}{2}kA^2 = \frac{1}{2}mv_{max}^2$

$v_{max} = 7.3$ m/s (at equilibrium position)

so $A^2 = \dfrac{\frac{1}{2}mv_{max}^2}{\frac{1}{2}k} = \dfrac{(120+52)(7.3)^2}{490} = 18.71$

and $A = \sqrt{18.71} = 4.32$ m

5. While taking a walk in the forest you see a bird singing on a tree branch 40 m away, and realize you can just barely hear the bird at that distance. As the bird continues to chirp at the same sound level, you move closer for a better look. How much sound power passes through your ear when you are 5m away? The cross sectional area of your ear canal is 2.3 cm^2. Answer in W.

a) 1.472×10^{-8} b) 1.472×10^{-10} c) 1.472×10^{-14} d) 1.472×10^{-16} e) None of these

at 40 m $I_{40} = I_0 = 10^{-12}\ W/m^2$ (threshold of hearing)

so power of bird $P = I_{40}\cdot(4\pi r^2)$ area of sphere of radius 40 m

$P = 10^{-12}\cdot(4\pi(40)^2)$

at 5m away this power goes through an area $A_5 = 4\pi(5)^2$

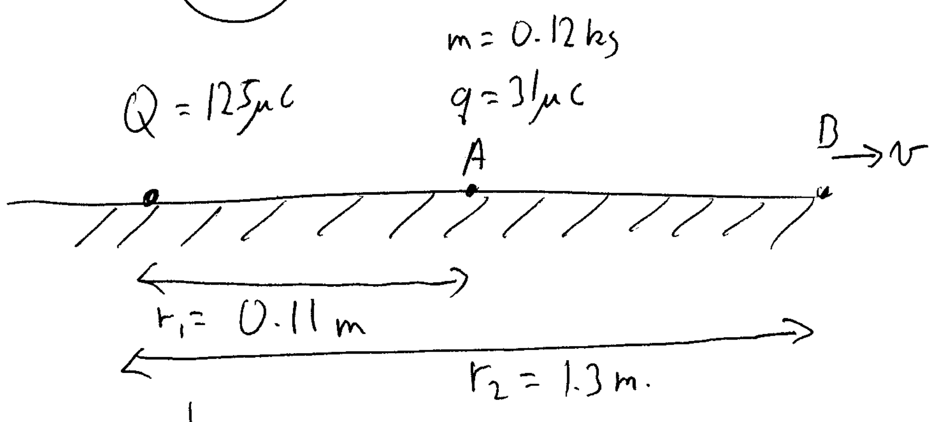
so $I_5 = \frac{P}{A_5}$ and to get power into ear.

$P_{ear} = I_5\cdot A_{ear}$ $A_{ear} = 2.3\ cm^2 = 2.3\times10^{-4}\ m^2$

so $P_{ear} = I_5\cdot A_{ear} = \frac{P}{A_5}A_{ear} = \frac{10^{-12}[4\pi(40)^2]}{4\pi(5)^2}\cdot 2.3\times10^{-4} = 1.472\times10^{-14}\ W/m^2$

6. A point charge (Q = +125 μC) is fixed onto a frictionless horizontal surface. A second point charge of mass m= 120 g and q= +31 μC is initially held on the same surface a distance of 11 cm away from Q, and then released. Find the speed of the second charge when it is 1.3 m away from the first charge. Answer in m/s

a) 0 b) 69.5 c) 289 d) 83.2 e) None of these



work done on charge q is

$W = -q\Delta V = -q(V_B - V_A) = -q\left[\frac{kQ}{r_2} - \frac{kQ}{r_1}\right]$

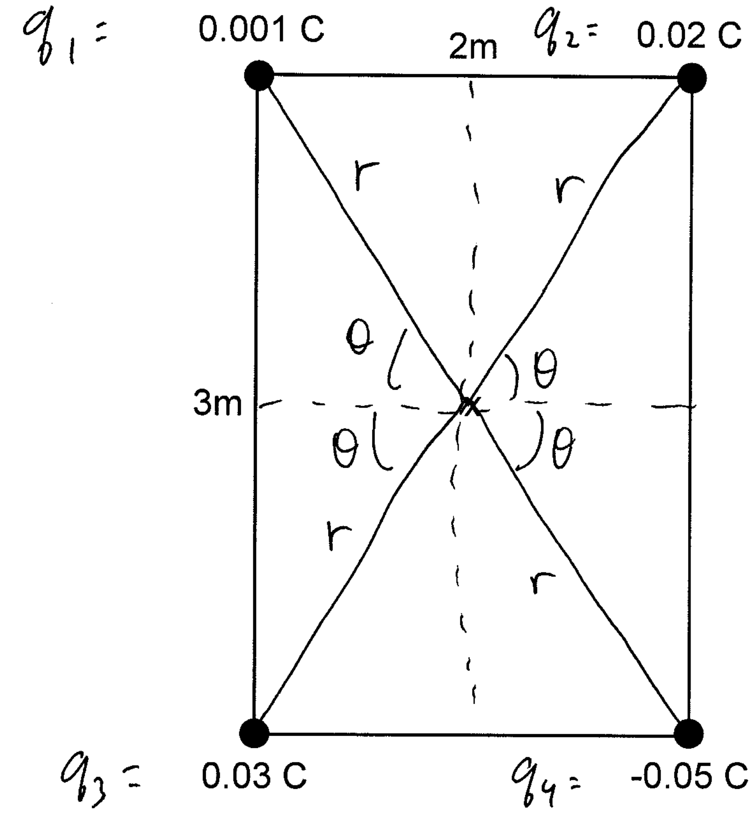
$= 290.2\ J$

W = change in kinetic energy

$W = K_f - K_i = K_f - 0 = \frac{1}{2}mv^2$

$v^2 = \frac{W}{\frac{1}{2}m} = \frac{290.2}{\frac{1}{2}\cdot 0.12} = 4836.9$, $v = \sqrt{4836.9} = 69.5$

7. Prof Mansour is sitting in the center of a rectangle, with sides of 2 m and 3 m respectively, surrounded by electrical charges as shown. He is desperately trying to hold a drink in his hand, indicated by the x. If the drink has a charge of 23 uC, what is the total force acting on the drink? Answer in N.



$\tan\theta = \frac{3/2}{2/2}$

$= 1.5$

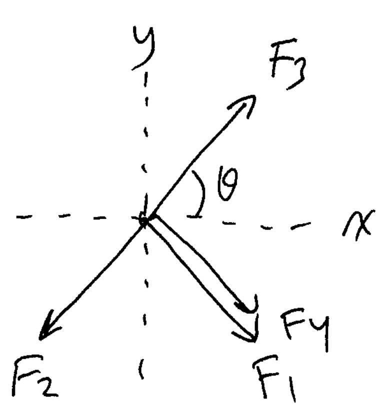
$\theta = 56.3°$

$r^2 = \left(\frac{3}{2}\right)^2 + \left(\frac{2}{2}\right)^2$

$= 3.25$

a) 3310 b) 3061 c) 3542 d)3783 e) None of these

Forces acting on x



in components

$$F_x = F_1\cos\theta - F_2\cos\theta + F_3\cos\theta + F_4\cos\theta$$

$$= \cos\theta\,(F_1 - F_2 + F_3 + F_4) = \cos\theta\left(\frac{k|q_1|}{r^2} - \frac{k|q_2|}{r_2} + \frac{k|q_3|}{r^2} + \frac{k|q_4|}{r^2}\right)q_{drink}$$

$$= \frac{k}{r^2}\cos\theta\left(|q_1| - |q_2| + |q_3| + |q_4|\right)q_{drink}$$

$$= \frac{9\times10^9}{3.25}\cos(56.3)\left(0.001 - 0.02 + 0.03 + 0.05\right)\cdot 23\times10^{-6}$$

$$= 2155.7\,N$$

$$F_y = -F_1\sin\theta - F_2\sin\theta + F_3\sin\theta - F_4\sin\theta$$

$$= \frac{k}{r^2}\sin\theta\left(-|q_1| - |q_2| + |q_3| - |q_4|\right)\cdot q_{drink}$$

$$= \frac{9\times10^9}{3.25}\sin(56.3)\left(-0.001 - 0.02 + 0.03 - 0.05\right)\cdot 23\times10^{-6} = -2172.55$$

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{(2155.7)^2 + (-2172.55)^2} = 3060.6\,N$$

8. A 21 μC charge is placed 33 cm to the left of a -105 μC charge. Find the distance from the 21 μC charge that a positive charge needs to be placed so the net electrostatic force on it is zero. Answer in m.

a) 0.37 b) 0.165 c) 5.0 d) 0.27 e) None of these

$q_1 = 21\mu C$ $q_2 = -105\mu C$

if force = 0, then $\vec{E} = 0$
this can't be in middle of 2 charges
try to the left

P

$\leftarrow x \rightarrow \leftarrow 0.33 \rightarrow$

field at P is $E = -\frac{kq_1}{x^2} + \frac{k|q_2|}{(x+0.33)^2} = 0$

so $\frac{kq_1}{x^2} = \frac{k|q_2|}{(x+0.33)^2}$ or $\frac{q_1}{x^2} = \frac{|q_2|}{(x+0.33)^2}$ or $105\times10^{-6}x^2 = 21\times10^{-6}(x+0.33)^2$

or $5x^2 = (x+0.33)^2 \Rightarrow x\sqrt{5} = x + 0.33$

$x(\sqrt{5}-1) = 0.33$

$x = 0.267\,m$

9. A proton moving at a speed of $2.3\text{x}10^6$ m/s enters a region in space where the electric field is uniform. The field points in a direction parallel to the velocity of the proton and in same direction. If the field strength is $3.4\ \text{x}10^7$ N/C find the speed of the proton after it has travelled 4mm into the field. Answer in m/s.

a) $1.6\text{x}10^8$ b) $3.2\text{x}10^7$ c) $5.6\text{x}10^6$ d) $7.4\text{x}10^6$ e) None of these

V_0

$E = 3.4\times10^7$

proton mass $m = 1.67\times10^{-27}$ kg
charge $q = 1.6\times10^{-19}$ C

$F = ma = qE$ so $a = \frac{qE}{m}$ acceleration

$= \frac{1.6\times10^{-19}\cdot 3.4\times10^{7}}{1.67\times10^{-27}}$

$= 3.2575\times10^{15}\,m/s^2$

Constant acceleration so use

$V^2 = V_0^2 + 2a\Delta x$

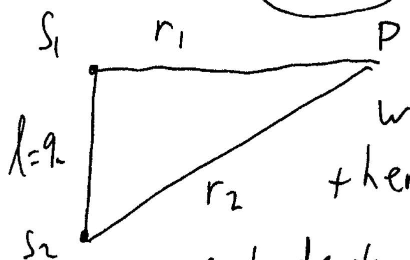
$= (2.3\times10^6)^2 + 2\cdot 3.2575\times10^{15}\cdot 0.004$

$= 3.135\times10^{13}$

$V = \sqrt{3.135\times10^{13}} = 5.6\times10^6\,m/s$

10. Two speakers are driven by the same amplifier with a frequency of 680 Hz. The two speakers are 9m apart. An observer, originally at the position of one of the speakers, starts moving away along a line perpendicular to the line connecting the two speakers. What is the distance the observer must travel to move between the locations of the 7th and the 8th interference minima (destructive interference) that the observer experiences. The speed of sound is 340 m/s. Answer in m.

a) 0.92 b) 1.53 c) 1.88 d) 0.50 e) 0.25



what n do we use for 7th, 8th minima?

wavelength $\lambda = v/f = \frac{340}{680} = 0.5\text{m}$

there are $\frac{l}{\lambda} = \frac{9}{0.5} = 18$ wavelengths between S_1 and S_2

get destructive interference when $(r_2 - r_1) = (n+\frac{1}{2})\lambda \quad n = 0,1,2,3\ldots$

so there are 18 minima along the line joining S_1 and S_2 $[(r_2-r_1) = \frac{1}{2}\lambda, \frac{3}{2}\lambda \ldots 17.5\lambda]$

so the closest minimum to S_1 corresponds to $n = 17$. $n = 17$

As we move towards point P from S_1, the first minimum will occur at $n = 17$, the 2nd at $n = 16$ and so on

$S_1 \cdot$ 17 16 15 14 13 12 11 10
1 2 3 4 5 6 7 8

so 7th minimum occurs at $n = 11$

8th minimum at $n = 10$

7th minimum at $r_{27} - r_{17} = (11 + \frac{1}{2})\lambda = 11.5\lambda$
8th minimum at $r_{28} - r_{18} = (10+\frac{1}{2})\lambda = 10.5\lambda$ } want $x = r_{18} - r_{17}$

so $r_{27} = r_{17} + 11.5\lambda \Rightarrow \sqrt{r_{17}^2 + 9^2} = r_{17} + 11.5\lambda \Rightarrow r_{17}^2 + 81 = r_{17}^2 + 23\lambda r_{17} + ((11.5)\lambda)^2$

$r_{28} = r_{18} + 10.5\lambda \quad \sqrt{r_{18}^2 + 9^2} = r_{18} + 10.5\lambda \quad r_{18}^2 + 81 = r_{18}^2 + 21\lambda r_{18} + ((10.5)\lambda)^2$

and $\lambda = 0.5 = \frac{1}{2}$

So $11.5 r_{17} = 81 - (11.5 \cdot 0.5)^2 \Rightarrow r_{17} = 4.1685$

$10.5 r_{18} = 81 - (10.5 \cdot 0.5)^2 \quad r_{18} = 5.0893$

$\Rightarrow x = r_{18} - r_{17} = 5.0893 - 4.1685 = 0.92\text{ m}$

11. 170 uniformly speaking students in classroom produce a sound level of 72 db. What is the sound level after 70 students leave the room? Answer in db.

a) 29.64 b) 68.14 c) 69.70 d) 73.47 e) None of these

Intensity of 170 students = 170 · Intensity of 1 or $I_{170} = 170 I_1$

Intensity of 100 students (70 left) $I_{100} = 100 I_1$

remember how logs work

$\beta_{170} = 10 \log \frac{I_{170}}{I_0} = 10 \log \frac{170 I_1}{I_0} = 72$

$\beta_{100} = 10 \log \frac{I_{100}}{I_0} = 10 \log \frac{100 I_1}{I_0} = ?$

$\beta_{170} - \beta_{100} = 10 \log \frac{170 I_1}{I_0} - 10 \log \frac{100 I_1}{I_0} = 10 \log \left[\frac{170 I_1 / I_0}{100 I_1 / I_0} \right]$

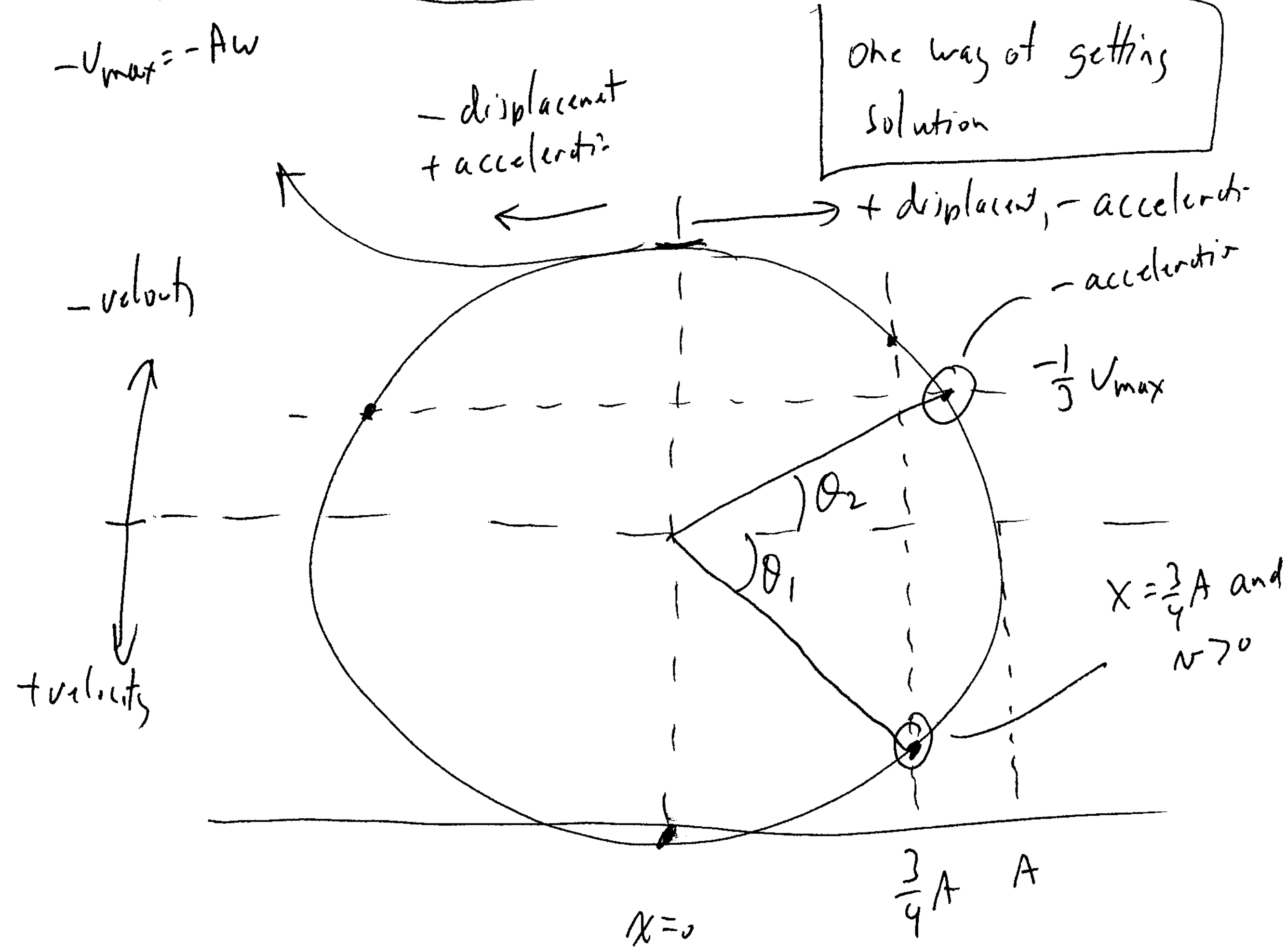
$= 10 \log \frac{170}{100} = 2.3$

So $\beta_{100} = \beta_{170} - 2.3 = 72 - 2.3 = 69.7\text{ dB}$

12. A mass connected to a horizontal spring executes SHM such that at a certain time the mass is located at x = 3/4 the amplitude while moving in the positive direction. 1.3 seconds later the mass is moving such that its velocity is -1/3 of the maximum velocity with a negative acceleration. If the mass of the particle is 0.3 g, find the spring constant. Answer in N/m.

a) 0.25 b) 2.00x10^{-4} c) 0.87 d) 2.64x10^{-5} e) None of these

One way of getting solution



$\cos\theta_1 = \frac{3/4\,A}{A} = \frac{3}{4}$ so $\theta_1 = 0.7227$ (remember radians)

$\sin\theta_2 = \frac{\frac{1}{3}V_{max}}{V_{max}} = \frac{1}{3}$ so $\theta_2 = 0.3398$

the particle travels an angle $\theta_1 + \theta_2$ in 1.3 seconds

so angular velocity $\omega = \frac{\theta_1 + \theta_2}{1.3} = \frac{0.7227 + 0.3398}{1.3} = 0.8173$ rad/s

and this is the same as angular frequency for SHO

$\omega^2 = k/m$ remember kg

so $k = \omega^2 m = (0.8173)^2 \cdot (0.0003)$

$= 2 \times 10^{-4}$ N/m

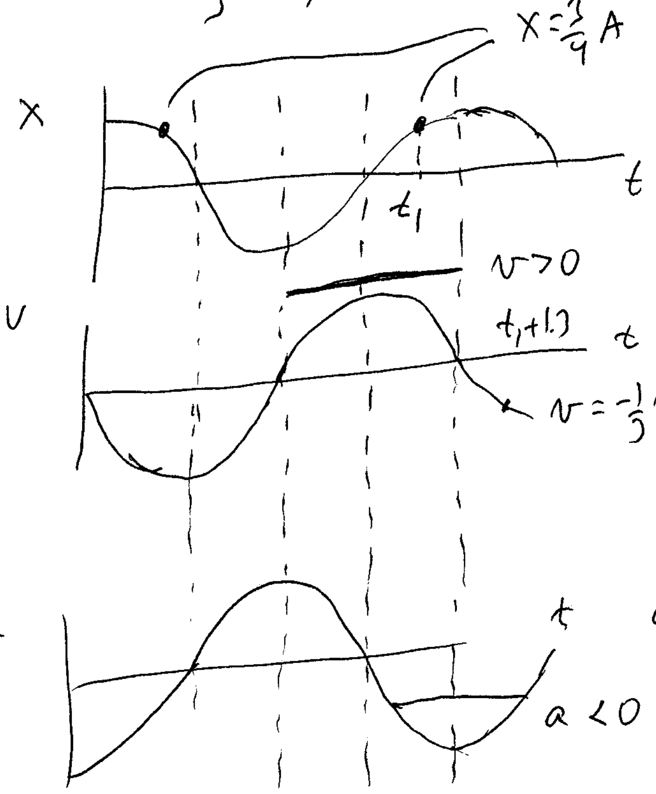
12. A mass connected to a horizontal spring executes SHM such that at a certain time the mass is located at x = 3/4 the amplitude while moving in the positive direction. 1.3 seconds later the mass is moving such that its velocity is -1/3 of the maximum velocity with a negative acceleration. If the mass of the particle is 0.3 g, find the spring constant. Answer in N/m.

a) 0.25 b) 0.087 c) $2.00\text{x}10^{-4}$ d) $2.64\text{x}10^{-5}$ e) None of these

One way of getting solution

at t_1 $x = \frac{3}{4}A$ $v > 0$

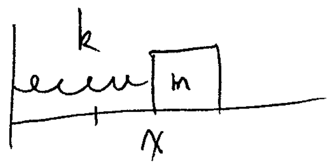
at $t_1 + 1.3$ $v = -\frac{1}{3} v_{max}$ $a < 0$



$x(t) = A\cos\omega t$

$v(t) = -A\omega\sin\omega t$ $v_{max} = A\omega$

$a(t) = -A\omega^2\cos\omega t$



$m = 0.0003\,kg$ $\omega^2 = k/m \Rightarrow k = \omega^2 m$

$\frac{3}{2}\pi < \omega t_1 < 2\pi$

$x(t_1) = \frac{3}{4}A = A\cos\omega t_1$

$x(t_1 + 1.3) = -\frac{1}{3}A\omega = -A\omega\sin[\omega(t_1+1.3)]$ $2\pi < \omega(t_1+1.3) < \frac{5\pi}{2}$

So $\frac{3}{4} = \cos\omega t_1$ $\omega t_1 = 0.7227$ or $2\pi - 0.7227$
$= 5.557 \Rightarrow$ between $\frac{3}{2}\pi$ and 2π

So $\omega t_1 = 5.557$ rad

and $\frac{1}{3} = \sin[\omega t_1 + \omega \cdot 1.3]$ between 2π and $\frac{5\pi}{2}$

So $\omega t_1 + 1.3\omega = 0.3398$ or $2\pi + 0.3398 = 6.62$ rad.

$5.557 + 1.3\omega = 6.62 \Rightarrow \omega = 0.8177$ rad/sec

$k = \omega^2 m = (0.8177)^2 \cdot 0.0003 = 2\times10^{-4}$

112 FORMULA SHEET

Simple Harmonic motion

$x = A\cos(\omega t + \varphi)$ A=amplitude

$\omega = \sqrt{\frac{k}{m}}$ mass and spring

Simple pendulum

$\omega = \sqrt{\frac{g}{\ell}}$

$\omega = 2\pi f = 2\pi/T$

Waves on a string

$v = \sqrt{\frac{F}{\mu}},\ F = Tension$

$v = \lambda f$

Sound waves

$v = \sqrt{\frac{B}{\rho}}$

$v = \sqrt{\frac{Y}{\rho}}$

speed of sound $v = 345 m/s$

$I = \frac{P}{4\pi r^2}$

$\beta(db) = 10\log\frac{I}{I_o},\quad I_o = 1.0x10^{-12}\ W/m^2$

Electrostatics

$F = k\frac{|q_1 q_2|}{r^2},\quad k = 8.99x10^9\ Nm^2C^{-2},\quad k = \frac{1}{4\pi\varepsilon_0}$

$\vec{F} = q\vec{E},\quad \Delta V = -\vec{E}.\vec{d}\ (Uniform\ Field)$

$V_Q = k\frac{Q}{r^2},\quad m_e = 9.11x10^{-31}$ kg

$m_p = 1.67x10^{-27}$ kg, $e = 1.6x10^{-19} C$