Physics 120 Final Examination

12 August, 1998 Name_____
Time: 3 hours Signature_____
Calculator and one formula sheet allowed Student number _____

Show complete solutions to questions 3 to 8.
This examination has 8 questions.

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Some useful data:

$c = 3.0 \times 10^8$ m/s $k_B = 1.38 \times 10^{-23}$ J/K

solar luminosity $= 3.9 \times 10^{26}$ J/s Earth-Sun distance $= 1.5 \times 10^{11}$ m

1 pc = 3.26 l.y. 1 l.y. $= 9.46 \times 10^{15}$ m

$I_{sphere} = (2/5)MR^2$ $I_{disk} = (1/2)MR^2$ (axes through the centre)

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1. (10 marks) Circle one answer in each of the following questions:

(i) What is the momentum of a particle of mass m and kinetic energy mc^2?

(a) mc (b) $\sqrt{2}mc$ (c) $(3/2)mc$ (d) $3mc$ (e) $\sqrt{3}mc$

(ii) How many neutrons are there in the beryllium nucleus produced in the reaction
$^4He + {}^4He \rightarrow Be + n$?

(a) 7 (b) 8 (c) 3 (d) 4 (e) none of (a)-(d)

(iii) A sample of radioactive material is observed to decrease to 1/4 of its initial activity in 16 seconds. What is the lifetime of the nuclei in the material (in seconds)?

(a) 11.5 (b) 8 (c) 16 (d) 4 (e) 5.5

(iv) Consider a gas of nuclei in a star. Which of the following nuclei would have the highest average speed?

(a) ^1H at 10^6 K (b) ^{16}O at 10^6 K (c) ^2H at 3×10^6 K (d) ^{12}C at 10^7 K
(e) ^{238}U at 10^6 K

(v) Having been pulled over by the police for running a red light, a driver claims that the light appeared green to him because of the Doppler shift. How fast would he have to be travelling to make such a claim? Take $\lambda_{red} = 700$ nm and $\lambda_{green} = 500$ nm.

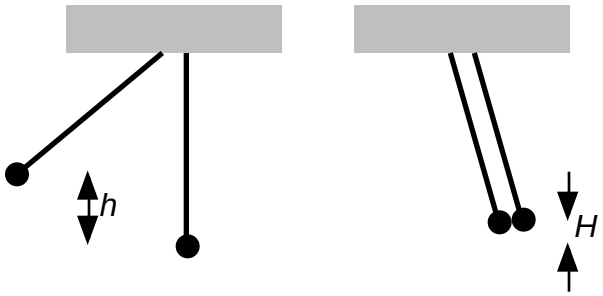
(a) $(5/7)c$ (b) $(2/7)c$ (c) c (d) $(7/5)c$ (e) none of (a)-(d)

2. (10 marks) Circle one answer in each of the following questions:

(i) A car of mass m travels at a speed v towards a stationary truck of mass $3m$. What is the speed of the centre-of-mass of the system?

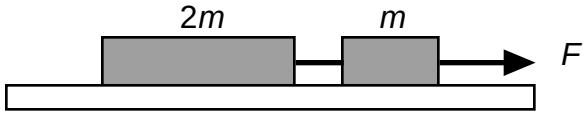
(a) v (b) $v/2$ (c) $3v/4$ (d) $v/4$ (e) $v/3$

(ii) Two identical masses are hung from massless strings of the same length. One mass is released from a height h above its free-hanging position, and strikes the second mass which is initially at rest. The two masses stick and move off together. To what height H do they rise?



(a) $3h/4$ (b) $h/4$ (c) h (d) $h/2$ (e) none of (a)-(d)

(iii) Two masses (m and $2m$) are attached to one another by a string as illustrated. A force F acts on mass m to accelerate the whole system. What is the magnitude of the net force on m?



(a) $F/3$ (b) F (c) $2F/3$ (d) $F/2$ (e) $3F/2$

(iv) A 50 gram piece of cake is dragged across a 2 meter long strip of sandpaper, losing about half of its mass by the time it reaches the end of the strip. Only just enough force is applied to the cake to keep it moving. How much work was done in moving the cake? (Take g = 10 m/s^2 and the coefficient of friction μ for cake on sandpaper to be 0.8.)

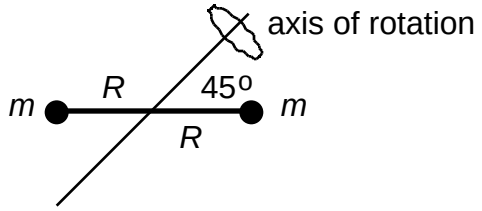
(a) 60 J (b) 0.3 J (c) 0.6 J (d) 0.4 J (e) 0.8 J

(v) Using a cable, an engine applies a constant force to move a mass m across a frictionless table in time t, starting from rest. The average power generated by the engine during this process is P. If the same engine delivered the same force to a mass $2m$ in moving it across the table, what would be the average power expended by the engine (in terms of the original P)?

(a) P (b) $\sqrt{2}\,P$ (c) $P/2$ (d) $P/\sqrt{2}$ (e) $2P$

3. (10 marks) Circle one answer in each of the following questions:

(i) What is the moment of inertia of two objects of mass m separated by a rigid rod of length $2R$, as in the diagram? Take the axis for the moment to intersect the rod at an angle of 45º.



(a) $(4/3)mR^2$ (b) $(1/3)mR^2$ (c) mR^2 (d) $4mR^2$ (e) none of (a)-(d)

(ii) On a calm day, the waves reaching a beach have an amplitude of 0.1 m. On a much windier day, the amplitude is 0.5 m, although the speed and wavelength of the waves is the same. What is the ratio of the power delivered by the waves on the windy day compared to that on the calm day?

(a) 1 (b) 25 (c) 5 (d) 1/5 (e) none of (a)-(d)

(iii) A uniform copper disk of radius R has a moment of inertia I around an axis passing through the centre of the disk perpendicular to its plane. If the radius of the disk were only $R/2$, but the thickness were the same, what would be the moment of inertia in terms of I?

(a) I (b) $I/2$ (c) $I/4$ (d) $I/8$ (e) $I/16$

(iv) Three objects with the same mass - a solid sphere, a solid disk and a hollow cylinder - roll without slipping up an incline plane. Each object has the same initial speed at the bottom of the plane. What is the maximum height that each object can attain?

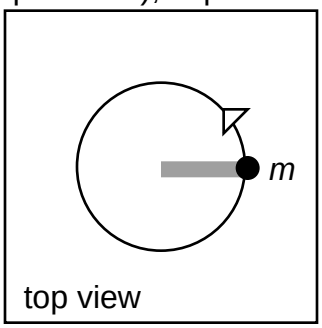
(a) $h_{\text{sphere}} < h_{\text{disk}} < h_{\text{cylinder}}$
(b) $h_{\text{sphere}} < h_{\text{disk}} = h_{\text{cylinder}}$
(c) $h_{\text{sphere}} > h_{\text{disk}} > h_{\text{cylinder}}$
(d) $h_{\text{sphere}} = h_{\text{disk}} = h_{\text{cylinder}}$
(e) none of (a)-(d)

(v) A pendulum consisting of a mass m attached to a massless string of length L is observed to have a period T. If the mass is halved to $m/2$, what is the new period in terms of the original one?

(a) $T/\sqrt{2}$ (b) T (c) $\sqrt{2}\,T$ (d) $2T$ (e) $T/2$

4. (15 marks) To an observer on the Earth, a distant star with the same luminosity as the Sun is observed to have an apparent brightness only 10^{-12} that of the Sun. What is the parallax of the star, in arc-seconds?

5. (10 marks) A massless spring has an unstretched length L and spring constant k The spring is placed horizontally on a frictionless surface. One end of the spring is attached to a fixed pivot, while a mass m is attached to the other end. The mass is given an impulse, causing it to execute a circular path with a period T. What is the extension x of the spring (from equilibrium), expressed in terms of m, L, T and k?

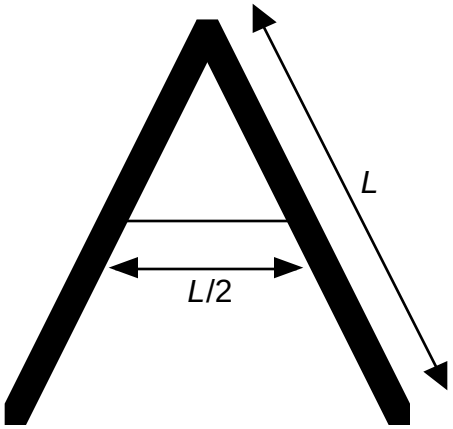


6. An object moves along the x-axis subject to a potential energy $V(x)$ of the form

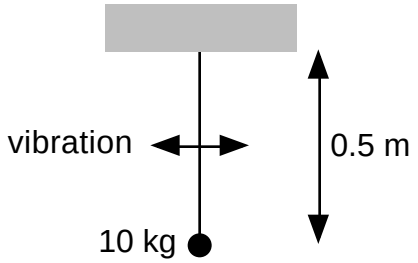
$$V(x) = V_0(-x^2/2 + x^4/4).$$

(i) (9 marks) At what values of x does the object feel no net force?
(ii) (6 marks) Suppose that the object is displaced very slightly from the position(s) that you calculated in part (i). Describe the motion of the object.

7. (15 marks) A step ladder consisting of two identical ladders, each of mass M and length L, is held together by a massless crossbar attached to the midpoints of the ladders. What force is exerted on the crossbar by each of the ladders, if the length of the crossbar is $L/2$? Assume that the forces at the top of the ladders are strictly horizontal, and ignore friction between the ladders and the floor. Solve for all angles, and express your answer in terms of mg only. Show a free-body diagram for one of the ladders.



8. A 10 kg mass is hung on the end of a wire of mass 10 grams and length L = 0.5 m, as illustrated. (Assume that g = 10 m/s.)
(i) (4 marks) What is the longest wavelength at which the wire vibrates when plucked?
(ii) (7 marks) What is the speed of a wave on the wire?
(iii) (4 marks) What is the lowest frequency corresponding to your answer in part (i)?



Answers:
1. (i) $\sqrt{3}\,mc$; (ii) 3; (iii) 11.5; (iv) ^{2}H; (v) $(2/7)c$.
2. (i) $v/4$; (ii) $h/4$; (iii) $F/3$; (iv) 0.6 J; (v) $P/\sqrt{2}$.
3. (i) mR^2; (ii) 25; (iii) $I/16$; (iv) sphere < disk < cylinder; (v) T.
4. 0.206 arc seconds.
5. $x = L/[kT^2/(4\pi^2 m) - 1]$
6. (i) -1, 0, 1; (ii) stable, unstable, stable.
7. $mg/\sqrt{3}$.
8. (i) 1 m; (ii) 71 m/s; (iii) 71 s^{-1}.