THE COLLEGES OF OXFORD UNIVERSITY

PHYSICS

Wednesday, 1 November 2006

Time allowed: 1 hour

For candidates applying for Physics, and Physics and Philosophy

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You may use any calculator.
No tables may be used.

Take $g = 10\,\mathrm{ms}^{-2}$.

Attempt all 3 sections and as many questions as you can.

Marks for each question are indicated in the right hand margin.
There are a total of 50 marks available.

Do NOT turn over until told that you may do so.

Section A: multiple choice (10 marks)

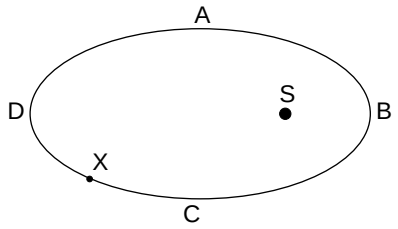
1. In the equation $x = ut + \frac{1}{2}at^2$ the term ut represents:

   A a speed **B** an acceleration
   C a displacement **D** an impulse [1]

2. A block of Niobium, a metal with density $8570\,\text{kg/m}^3$, has sides of length 3 cm, 4 cm and 5 cm. What is the maximum pressure that can be exerted by this block when it is stood upright on one of its faces?

   A 4.3 kPa **B** 430 Pa
   C 2.6 kPa **D** 510 kPa [1]

3. The diagram below shows the approximate orbit of the dwarf planet Eris (X) around the sun (S).



   Which of the following statements is **false**?

   A Eris moves fastest at point D.
   B Eris moves at the same speed at points A and C.
   C Eris moves in an ellipse with the sun at one focus.
   D The potential energy of Eris changes during the orbit. [1]

4. A hollow toy boat is floating in a bath. If you take a teaspoon full of water out of the bath and put it in the boat, what happens to the water level in the bath?

   A The level goes down.
   B The level goes up.
   C The level stays the same.
   D There isn't enough information to say. [1]

5. In quantum mechanics the de Broglie wavelength of an object depends on its momentum according to $\lambda = h/p$ where h is Planck's constant. Protons of charge e and mass m are accelerated from rest through a potential V. What is their de Broglie wavelength?

A $2h/\sqrt{meV}$ **B** $h/\sqrt{2meV}$
C $h\sqrt{meV}$ **D** h/eV [1]

6. A car accelerates steadily from 0 m/s to 20 m/s in a distance d and a time t. Another car takes a time $2t$ to accelerate steadily from stationary to the same final velocity. What distance does the second car cover during the new acceleration?

A $d/4$ **B** $d/2$
C d **D** $2d$ [1]

7. An alien civilization is in the business of building custom solar systems. Their basic model has five planets in circular orbits at distances D that are perfect square multiples of a basic length, so that they are in the ratio 1:4:9:16:25. For this model the year lengths Y of the planets are in ratios 1:8:27:64:125. How are D and Y related?

A $Y/D = k$ **B** $D = k\sqrt{Y}$
C $Y = kD\sqrt{D}$ **D** $Y^3/D^2 = k$ [1]

8. A Martian attempts to measure his mass using a set of bathroom scales in his house on Mars, and gets a reading of 93 kg. Unfortunately his scales were designed for use on Venus. Given that the gravitational strengths at the surface of Mars and Venus are 3.8 N/kg and 8.8 N/kg respectively, what is his true mass?

A 40 kg **B** 106 kg
C 215 kg **D** 245 kg [1]

9. When a metal bar is cooled it contracts. Which of the following is true?

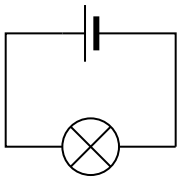
A The density and mass increase.
B The density increases and the mass remains constant.
C The density and mass are unchanged.
D The mass remains constant and the density decreases. [1]

10. A hot air balloon is descending at a steady speed of 11 m/s. The pilot drops a sandbag, which takes 7 s to fall to the ground. What was the height of the balloon when the sandbag was released?

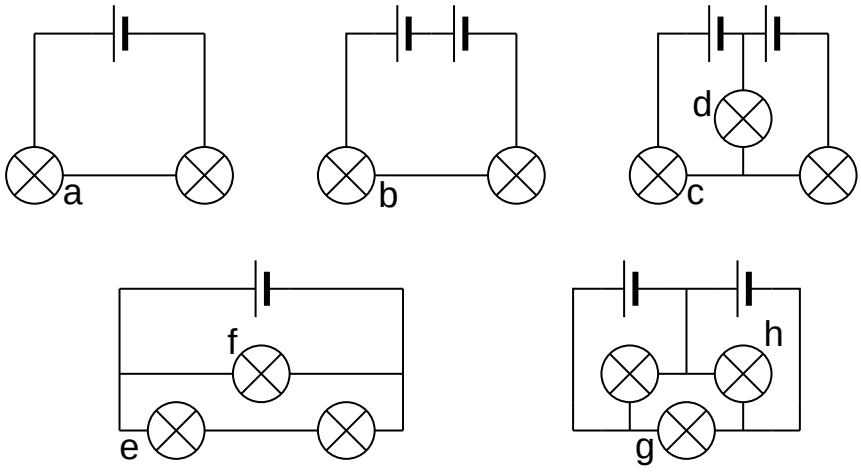
A 168 m **B** 245 m
C 322 m **D** 528 m [1]

Section B: written answers (20 marks)

11. The diagram below shows a circuit in which the bulb lights up with normal brightness.



In the circuits below the bulbs and cells all have the same specifications as the bulb and cell shown above.



Determine whether the bulbs marked by letters in these circuits are brighter than normal, normal, dimmer than normal, or off. [8]

12. While exploring the north pole of Mars an astronaut stumbles into a cave, containing a pool of glowing liquid and a collection of coloured cubes. Lacking any proper instruments she uses her spare oxygen tank as a measure and determines that

    (a) A red cube and a green cube together are as long as the tank.

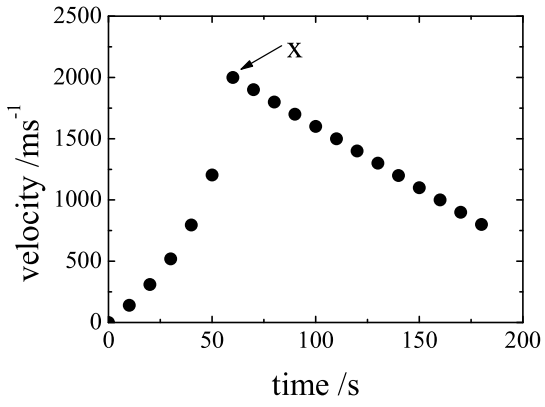
    (b) Two green cubes and a blue cube together are twice as long as the tank.

    (c) A red cube and a blue cube together are as long as two green cubes.

    (d) A red cube, a green cube and a blue cube together weigh the same as the tank.

    She also tries dropping the cubes into the pool, and notices that they all float with half their volume exposed. On returning to her base she discovers that her tank is 35 cm long and has a mass of 20 kg. Find the density of the glowing liquid. [6]

13. The graph below shows the velocity of a rocket as a function of time.



    (a) What has happened at point X? [1]

    (b) When is the acceleration of the rocket a maximum? Suggest an explanation of this. [2]

    (c) Describe the subsequent motion of the rocket. [2]

    (d) How in principle would you determine from this graph the maximum height reached by the rocket? [1]

Section C: long question (20 marks)

14. This problem concerns the mathematical treatment of a simple model of an electric toy car of mass m, which is initially stationary. The batteries in the car can be considered as an electrical power source with constant power P. You may neglect air-resistance and other experimental imperfections in the calculations.

    (a) Suppose that the car is placed on a level surface and that the motor can be treated as a device which converts electrical energy directly into kinetic energy. Calculate the kinetic energy of the car as a function of time, and hence its velocity as a function of time. [3]

    (b) Hence calculate the acceleration of the car and the distance traveled by the car as a function of time. [4]

    (c) Find the limiting value of the velocity at very large times and comment on whether your result seems reasonable. [2]

    (d) Find the limiting value of the acceleration at very large and very small times and comment on whether your results seem reasonable. [4]

    (e) Instead of driving the car forward the motor could be used to lift the car up a vertical rope. Calculate the height which the car can reach as a function of time, and hence calculate the velocity at which it climbs the rope. [3]

    (f) The calculation in part (e) ignored the fact that as the car is moving then some of the motor's power must be used to give kinetic energy to the car. Assuming that the approach you used in part (e) is correct, calculate the ratio between the kinetic energy and the potential energy of the car climbing the rope as a function of time. Use your result to determine under what circumstances it is reasonable to ignore kinetic energy in this way. [4]

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MATHEMATICS FOR PHYSICS

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1. Evaluate
   (i) $2007^2 - 2006^2$ precisely;
   (ii) $1.001^6 - 1.001^5$ to one significant figure. [3]

2. Find the gradient of the line joining the points $(4, 8)$ and $(5, -2)$. [2]

3. Find all the values of x for which
   (i) $\log_e(e^{3x}) = 6$;
   (ii) $\log_3 x^2 = 2$; [3]

4. Simplify
$$13 \sin\left[\tan^{-1}\left(\frac{12}{5}\right)\right].$$
[3]

5. Sketch the functions
   (i) $\sin^2 x$;
   (ii) $\dfrac{1}{x^2 - 1}$. [8]

6. Circle A has a radius which is 1 cm bigger than circle B, and its area is $2\pi\,\text{cm}^2$ bigger. Find the radii of the two circles. [4]

7. Three dice are thrown, one after the other. Calculate the probability that
   (i) all three dice give a six;
   (ii) all three dice give the same number;
   (iii) only the third die gives a six. [3]

8. The volume of a spherical balloon increases by $1\,\text{cm}^3$ every second. What is the rate of growth of the radius when the surface area of the balloon is $100\,\text{cm}^2$? [3]

9. Find the area between the curve $y = |x^n|$, where n is a positive constant, the line defined by $y = -2$, and the lines defined by $|x| = 2$. [5]

10. Sum the following series:
    (i) $1 + e^{y} + e^{2y} + e^{3y} + \cdots$, where $e^{y} \ll 1$;
    (ii) $\log_2 1 + \log_2 2 + \log_2 4 + \cdots + \log_2 2^n$. [4]

11. Identify and classify the stationary points of the function

$$y = 5 + 24x - 9x^2 - 2x^3.$$

[6]

12. In the figure below, the radius of the larger circle is twice that of the smaller circle. Find an expression for the fraction of the area of the square which is occupied by the two circles. [6]