THIRD AUSTRALIAN NATIONAL PHYSICS COMPETITION

THEORY EXAM

Thursday December 1, 2:00 pm, RSPHYSSE, ANU

Time allowed: 3 hours + 10 minutes reading time

Attempt as many problems as you like. The mark value for each problem is written next to the question number. You will only have time to finish a fraction of the questions.

There are two kinds of problems.

(A) **Shorter Quantitative Problems (1-17):** for which a numerical answer is required. NO WORKING FOR THES E PROBLEMS WILL BE MARKED. ANSWERS MUST BE WRITTEN ON THE ANSWER SHEET PROVIDED - IN THE UNITS ASKED FOR TO THE EXACT NUMBER OF SIG FIGS ASKED FOR. For these problems you either get the answer right (and full marks) or nothing.

(B) **Longer Problems (18-31):** which are more open-ended. For these the working will be marked and pa rtial marks will be awarded if it is clear you know what you are doing (but perhaps made a silly mistake). It is important you write clear and legible answers to these problems. In some cases there is a "correct" answer. In other cases the problem is very open-ended, and may require creatitivity and approximation - and there is no right answer.

AFTER MARKING ALL ANSWER SHEETS WILL BE CREMATED

Calculators and graph paper may be used, as well as one book.

A few constants

Constant	Notation	Value
permeability of vacuum	μ_0	$4\pi \cdot 10^{-7}\ G \cdot m^{-1}$
permittivity of vacuum	ε_0	$8.85418782 \cdot 10^{-12}\ F \cdot m^{-1}$
Speed of light	c	$299\,792\,458\ m \cdot s^{-1}$
Elementary charge	e	$1.6021892 \cdot 10^{-19}\ Cl$
Plank constant	h	$6.626176 \cdot 10^{-34}\ J \cdot s$
	$\hbar = h/2\pi$	$1.0545887 \cdot 10^{-34}\ J \cdot s$
Classical radius of electron	r_e	$2.85 \cdot 10^{-15}\ m$
Avogadro number	N_A	$6.0220943 \cdot 10^{26}\ kmol^{-1}$
Mass of electron	m_e	$9.109534 \cdot 10^{-31}\ kg\ [0.511\ MeV]$
Mass of proton	m_p	$1.6726485 \cdot 10^{-27}\ kg\ [938.3\ MeV]$
Mass of neutron	m_n	$1.6749543 \cdot 10^{-27}\ kg\ [939.6\ MeV]$
Molar gas constant	R	$8.314\ J \cdot K^{-1} \cdot mol^{-1}$
Boltzmann constant	k	$1.380662 \cdot 10^{-23}\ J \cdot K^{-1}$
Newton constant	$\gamma,\ G$	$6.6720 \cdot 10^{-11}\ N \cdot m^2 \cdot kg^{-2}$

Some Celestial Data

	Average radius	Mass	Average distance to sun	Year (in earth days)
Sun	$7.0 \cdot 10^8\ m$	$1.98 \cdot 10^{30}\ kg$		
Venus	$6.2 \cdot 10^6\ m$	$4.9 \cdot 10^{24}\ kg$	$1.0811 \cdot 10^{11}\ m$	227.70 days
Earth	$6.4 \cdot 10^6\ m$	$5.98 \cdot 10^{24}\ kg$	$1.4946 \cdot 10^{11}\ m$	365.26 days
Mars	$3.4 \cdot 10^6\ m$	$6.5 \cdot 10^{23}\ kg$	$2.277 \cdot 10^{11}\ m$	686.98 days
Moon	$1.7 \cdot 10^6\ m$	$7.4 \cdot 10^{22}\ kg$	(to earth) $3.8 \cdot 10^8\ m$	–

A - Easier Quantitative Problems: No partial marks given

(ALL ANSWERS TO BE GIVEN TO 2 SIGNIFICANT FIGURES UNLESS OTHERWISE STATED)

Problem 1. *(2 Marks) A 25-Watt bulb is designed for 120 Volt circuit. How much power does it use in a 240 Volt circuit? (Answer in Watts)*

Problem 2. *(2 Marks) A car with mass* $m = 3.5$ *tonnes gains* 100.0 *km.p.h. in* 100.0 *meters. What is the power developed by its engine (ignoring all losses)? (Answer in kW)*

Problem 3. *(4 Marks) A metal ball with mass* $m = 300.0$ *gram and radius* $r = 2.5$ *cm is suspended on a smooth vertical wall with the help of a thread with the length* $\ell = 4.0$ *cm. Find the magnitude of the force of the ball on the wall in Newtons.*

Problem 4. *(4 Marks) A man with mass* $m = 60.0$ *kilogram moves from the prow of a boat to its stern. The boat has the length* $\ell = 3.0$ *meters and mass* $M = 120.0$ *kilogram. How far does the boat move in metres due to this process?*

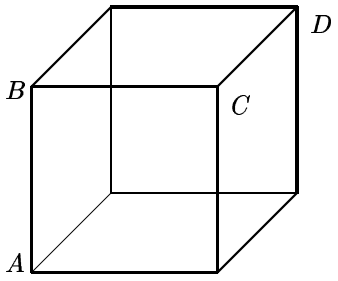
Problem 5. *(5 Marks) A small elastic ball rolls with the speed* $v = 1.0$ *m/s toward a well with depth* $h = 5.0$ *metres and diameter* $\ell = 15.0$ *cm . How many times does the ball knock the walls of the well before it reaches the bottom?*

Problem 6. *(5 Marks) A pendulum clock is exact on Wanda beach in Sydney. How many seconds per day will it be slow on Telstra Tower (the height of Telstra Tower's top floor above the sea is about 1 km)? Answer in seconds/day.*

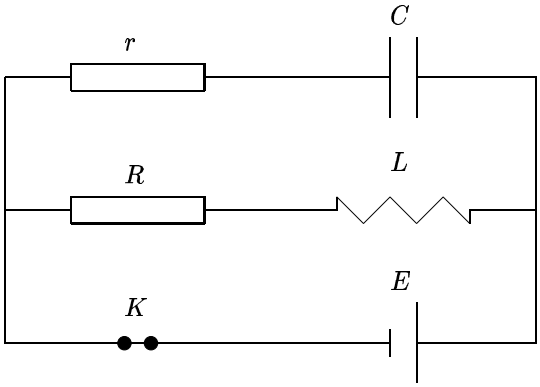
Problem 7. *(8 Marks) A house in the middle of nowhere (i..e Siberia, Winter). At the noon the temperature outside is* -20.0° *C and the temperature inside is* $+20.0^\circ$ *C. At the midnight the temperature outside is* -40.0° *C and the temperature inside is* $+10.0^\circ$ *C.*

Find the temperature of the heater heating the house in degrees C.

Problem 8. *(10 Marks) Each edge of a cube has resistance* $\rho = 1.0$ *Ohms. Find the resulting resistance* R_{AD} *in Ohms.*



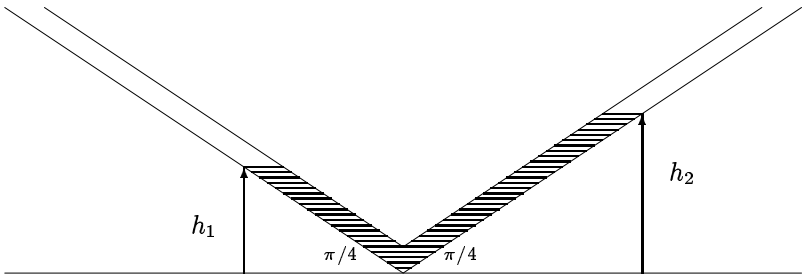
Problem 9. *(10 Marks) Find the heat produced in r after disconnecting of the switch K. Data are: $r = 1.0\ Ohm$, $R = 2.0\ Ohm$, $C = 3.0 \cdot 10^{-3}\ F$, $L = 5.5 \cdot 10^{-3}\ H$, $E = 12.0\ V$. Heat in Joules.*



Problem 10. *(10 Marks) A photon with energy $E_0 = 1.0 \times 10^{-20}$ Joules falls on a motionless perfect mirror with a small mass $m = 1.0 \times 10^{-5}$ kg, and then reflects. Find the resulting speed of the mirror in metres/second.*

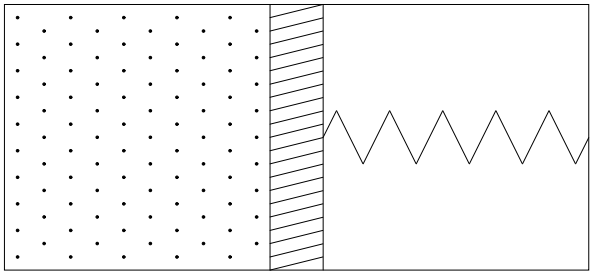
Problem 11. *(10 Marks) Evidence of a double star is a periodic splitting of their spectral lines. In a particular example, the maximal splitting of the hydrogen line 4340.47 Å is 9.03 Å. This happens once in 3 days 2 hours and 46 minutes. Assuming that the stars are equal, find the distance between the stars in metres.*

Problem 12. *(10 Marks) The simplest "accelerometer" may be designed as a thin tube filled by water as it is shown. The water levels appeared to be $h_1 = 1.0$ metres and $h_2 = 1.5$ meters. Find magnitude of the the acceleration in metres per second.*

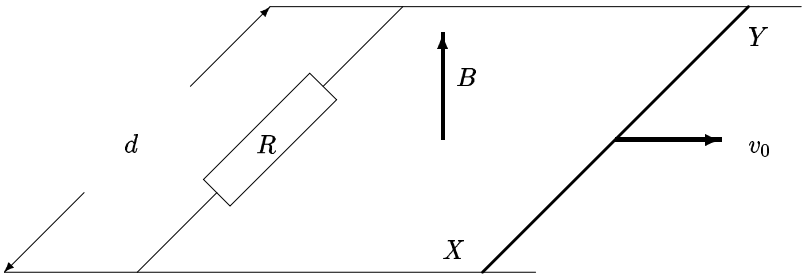


Problem 13. *(10 Marks) A table has radius 1.00 metres. At what height above it should a lightglobe be suspended so as to give maximum illumination at the edges of the table?*

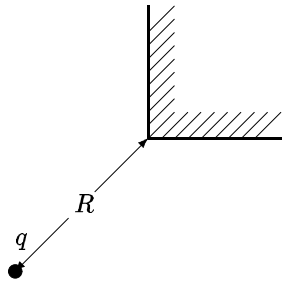
Problem 14. *(10 Marks) An isolated cylinder is divided by a piston connected to the right side of cylinder by a spring. The natural length of the spring equals the length of the cylinder. One mole of an ideal monomolecular billard-ball gas is placed to the left half of cylinder. Find the heat capacity of the system in Joules per degree C.*



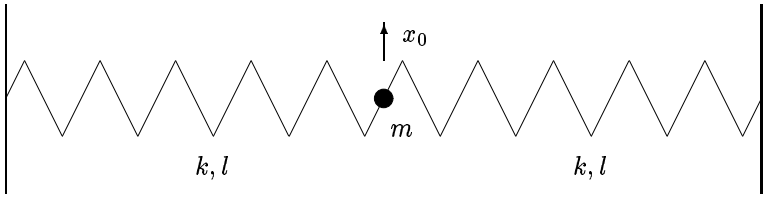
Problem 15. *(10 Marks) The distance between horizontal rails is* $d = 1.0$ *metres. A conducting rod* XY *with mass* $m = 0.10$ *kg may slide along the rails. The rails are connected by resistance* $R = 2.0$ *Ohms and placed in a vertical magnetc field* $B = 0.050$ *Tesla. The rod is given with initial velocity* $v_0 = 0.10$ *m/s. Find the distance moved by the rod in metres.*



Problem 16. *(20 Marks) A point-like charge* $q = 1.0$ *C is outside the metallic corner at the distance* $R = 1.0$ *metres. Find the magnitude of the force acting on* q *in Newtons. The metallic conductor extends infiinitely in the up and right directions and also out of the page.*



Problem 17. *(18 Marks) A body* $m = 1.0$ *kg is situated between two un-stretched springs of length* $l = 2.0$ *metres and spring constant* $k = 400.0$ *N/m . The body is moved* up *to a small distance* $x_0 = 0.0010$ *metres from the horizontal line and then released. There is no gravity in this problem.Find the period of oscillations CORRECT TO 1 SIGNIFICANT FIGURE in seconds.*



B- More Difficult Problems: Partial Marks Given. Working will be marked.

Problem 18. *(5 Marks) Two masses of salt, each of mass m are dissolved in two equal quantities of water of volume V. In one case the salt is in the form of a large crystal and in the other it is in the form of a fine powder. When the salt is dissolved will the temperature change in the two systems be different? If so why?*

Problem 19. *(5 Marks) An ordinary helicopter has a tail rotor at the back. Use the physics you know to explain why the rotor is needed.*

Problem 20. *(8 Marks) You are standing in an ordinary room. You notice that the shadow cast by your feet is much sharper than that cast by your head. Why is this?*

Problem 21. *(10 Marks) A homogeneous constant magnetic field B is directed vertically. A particle with mass m and charge q is suspended on a thread of the length L. The particle rotates with a measured period T. Find the radius of the trajectory. The thread is constantly tight.*

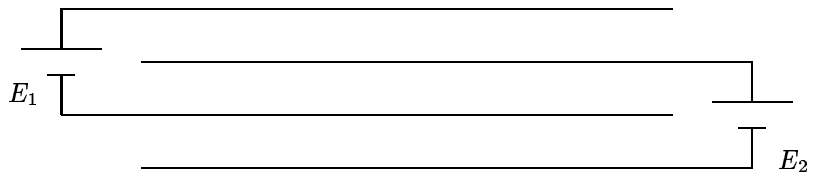
Problem 22. *(10 Marks) A spider and a fly sit on the surface of a crystal ball. Where the fly must sit so that the spider can see her? Index of crystal refraction is $n = 1.414213562$.*

Problem 23. *(12 Marks) A bare electric wire is carrying a direct current. Is there an electric field near the surface of this wire? Please explain why or why not.*

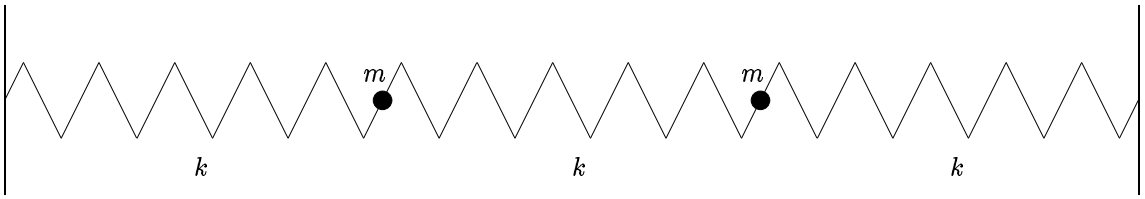
Problem 24. *(15 Marks) The temperature of sun's corona is $6000\ K$. Why do hydrogen atoms do not leave the sun? Please explain in semi-quantitative terms.*

Problem 25. *(15 Marks) You know that for a 1 dimensional quantum harmonic oscillator the energy eigenspectrum is $E_n = \hbar\omega(n + \frac{1}{2})$, where $n = 0, 1, 2$ etc. . Use this result to find the energy eigenspectrum for the 1 dimensional potential where the right side $x > 0$ is harmonic (parabolic) and the left side $x < 0$ is infinite and thus forbidden to the particle. Explain carefully how you get this answer.*

Problem 26. *(18 Marks) Four equivalent equidistant plates are connected to EMFs E_1 and E_2 as shown. Find the voltage between adjacent plates*

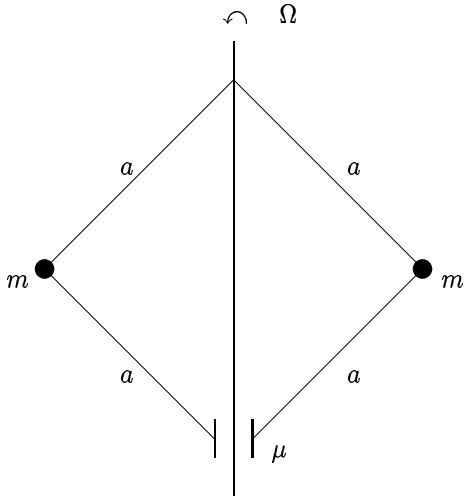


Problem 27. *(15 Marks) Find the frequencies of normal horizontal oscillations (spectrum) of two bodies m on three springs k.*



Problem 28. *(20 Marks) A bus starts moving along a straight road from the center of a big field with the speed V. You are somewhere in the field, your speed is $v < V$. Draw a region from where you can catch the bus.*

Problem 29. *(20 Marks) The system shown in the figure has been untwisted with a (big enough) angular velocity Ω (note the mass of the clutch μ). Find the frequency of small oscillations of this system in the usual gravitational field g.*



Problem 30. *(20 Marks) A particle is projected from a platform with speed V and elevation β. On the platform is a telescope with fixed angle of elevation α. The platform moves horizontally in the plane of the particle's motion so as to keep the particle always in the centre of the field of view of the telescope. Find the initial speed of the platform and the accelaration of the platform. [Cambridge Mathematical Tripos, Wed. Jan. 2, 1878, 9 to 12]*

Problem 31. *(40 Marks) A thin, heavy, uniform cyclindrical rod of length L rests partly within a smooth hemispherical bowl of radius R. The bowl is glued to a table with the vertex of the bowl downward. Find the position of equilibrium of the rod and for a fixed R give the limits on L. [Routh, Analytical Statics,, section 125]*