2010 HSC Physics Exam

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Question 1

C.

Orbital speed is given by

$$\begin{aligned}\frac{m_S v_o^2}{r} &= \frac{GM_E m_S}{r^2}\\ v_o &= \sqrt{\frac{GM_E}{r}}\end{aligned}$$

so a smaller radius of orbit means a larger orbital speed. The period of orbit is given by

$$T = \frac{2\pi r}{v_o}$$

which when substituted into the equation for orbital velocity yeilds Kepler's 3rd law

$$\frac{r^3}{T^2} = \frac{GM_E}{4\pi^2}$$

from which we see that a larger radius means a longer period of orbit.

Question 2

D.

Question 3

A.

$$\begin{aligned}t_v &= \frac{t_0}{\sqrt{1-\left(\frac{v}{c}\right)^2}}\\ t_0 &= \left(1.0\times 10^{-6}\,\mathrm{s}\right)\sqrt{1-0.9999^2}\\ &= 1.4\times 10^{-8}\,\mathrm{s}(2s.f.)\end{aligned}$$

Question 4

B.

The straightforward way to do this question is to note that the KE must initially be a local max (it gets slower as it moves upward) and that, as the horizontal component of the velocity is constant with time, the KE can never pass through zero. Only B satisfies these conditions.

In more detail, the relationship between velocity and time for projectiles is linear for the vertical component

$$v_y = u_y - gt$$

and constant for the horizontal component. For an angle of 45^o $u_y = u_x = u/\sqrt{2}$. The relationship between kinetic energy and the horiztontal and vertical components of the velocity is

$$\begin{aligned} KE &= \frac{m}{2}\left(v_x^2 + v_y^2\right) \\ &= \frac{m}{2}\left(\frac{u^2}{2} + \left(\frac{u}{\sqrt{2}} - gt\right)^2\right) \\ &= \frac{m}{2}\left(u^2 - gt\frac{u}{\sqrt{2}} + g^2t^2\right) \end{aligned}$$

which is a concave up parabola with a y-intercept of $mu^2/2$.

Question 5

D.

$$\begin{aligned} v &= \frac{d}{t} \\ &= \frac{5 \times 2\pi \times 1\,\mathrm{m}}{3\,\mathrm{s}} \\ &= \frac{10\pi}{3}\,\mathrm{ms}^{-1} \end{aligned}$$

and

$$\begin{aligned} F_c &= \frac{mv^2}{r} \\ &= \frac{(0.2\,\mathrm{kg}) \times \left(\frac{10\pi}{3}\,\mathrm{ms}^{-1}\right)^2}{1\,\mathrm{m}} \\ &= 22\,\mathrm{N} \end{aligned}$$

Question 6

B.

An experiment is valid if its design allows it to sucessfully test a desired hypothesis. In this case, Michelson and Morely aimed to measure the velocity of the earth relative to the aether, and their experiment was valid in that it correctly utilised interference effects to produce an experimental design that was certainly accurate enough to measure the directional dependence of the velocity of light that was anticipated given the expected value of the velocity of the earth relative to the aether.

Question 7

D.

$$\begin{aligned} W_E &= 9.8\,\mathrm{ms}^{-2} \times 2\,\mathrm{kg} \\ &= 19.6\,\mathrm{N} \end{aligned}$$

and

$$\begin{aligned} W_E &= 3.6\,\mathrm{ms}^{-2} \times 2\,\mathrm{kg} \\ &= 7.2\,\mathrm{N} \end{aligned}$$

Question 8

C.

Back emf is proportional to the speed of rotation of the motor, and opposes supply emf. The current that flows is given by

$$I = \frac{\varepsilon_{supply} - \varepsilon_{back}}{R_{coils}}$$

so when the motor slows down, back emf decreases, the current increases as does the power (and so heat) dissipated in the coils.

Question 9

C.

For a particular amount of power that is to be transmitted, $P = VI$ we can choose to transmit either at high voltage and low current or vice-versa. The power dissipated in the transmission lines is given by $P = I^2R$ so is minimised by minimising the current.

Question 10

D.

The secondary is connected to the load, the primary to the AC voltage source, and there are more turns in the secondary coil than in the primary, so it is a step up transformer.

Question 11

There is not enough information to choose between B and D. Let me provide an explanation that will be accesible to anyone who is familiar with calculus.

The emf induced in the inner ring is given by

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

From the information in the question we can take $\frac{d\Phi_B}{dt} > 0$ so $\varepsilon < 0$, i.e. that the current flows in the opposite direction in the inner ring to the outer ring. What the question does *not* tell us however, is how $\frac{d\Phi_B}{dt}$ is changing with time, i.e. it does not tell us the sign of the second derivative of the current in the outer ring. There are 3 possibilities:

1. The current in the outer ring is increasing at *constant* rate, in which case $\varepsilon < 0$ and is constant, so the current in the inner ring is also constant.

2. The current in the outer ring is increasing at an *increasing* rate in which case $\varepsilon < 0$ and is getting more negative with time, in which case the current in the inner ring is increasing in magnitude with time, or

3. The current in the outer ring is increasing at a *decreasing* rate, in which case $\varepsilon < 0$ and is getting more positive with time, in which case the current in the inner ring is decreasing in magnitude with time.

Question 12

B.

$$\begin{aligned} v &\propto \sqrt{r} \\ v^2 &\propto r \end{aligned}$$

Thus v^2 versus r will be a straight line graph.

Question 13

D.

Question 14

C.

Question 15

B.

$$\begin{aligned}\frac{mv^2}{r} &= qvB \\ r &= \frac{mv}{qB}\end{aligned}$$

If $B_{new} = 2B$ then

$$\begin{aligned}r_{new} &= \frac{mv}{qB_{new}} \\ &= \frac{mv}{q2B} \\ &= \frac{r}{2}\end{aligned}$$

Question 16

A. By the right hand rule.

Question 17

D. The electric and magnetic fields must be perpendicular to provide equal and opposite forces on the electron beam.

Question 18

C.

Question 19

B.

Question 20

B. The wiring in B produces a north pole near the coils on the right and a south near the coils on the left, with current travelling from the positive terminal to the negative terminal through the coil, so by the right hand rule this combination will result in a clockwise rotation.

Question 21

Angle A is too shallow and the spacecraft may skip off the atmosphere. Angle C to too steep and the g forces resulting from the higher deceleration may be too great for the spacecraft and its (possible) occupants to survive.

Question 22

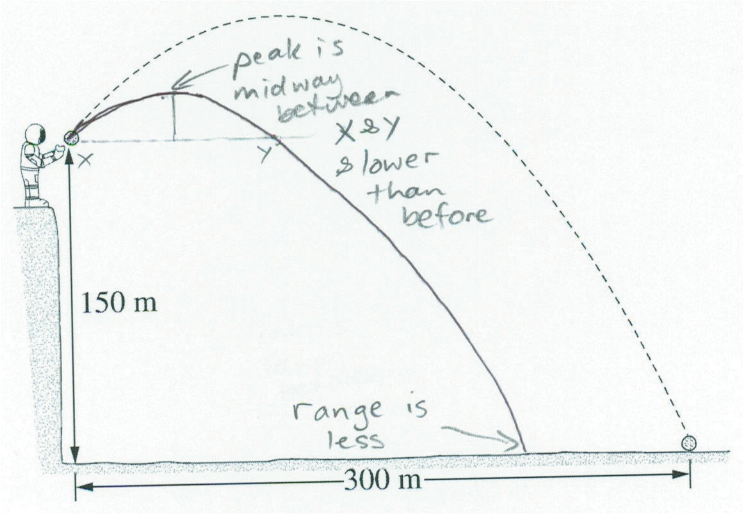
(a)

$$\begin{aligned} v_x &= \frac{\Delta x}{t} \\ &= \frac{300\,\mathrm{m}}{21\,\mathrm{s}} \\ &= 14.3\,\mathrm{ms}^{-1} \end{aligned}$$

(b)

$$\begin{aligned} \Delta y &= u_y t + \frac{at^2}{2} \\ u_y &= \frac{\Delta y}{t} - \frac{at}{2} \\ &= \frac{-150\,\mathrm{m}}{21\,\mathrm{s}} + \frac{(1.6\,\mathrm{ms}^{-2}) \times (21\,\mathrm{s})}{2} \\ &= 9.66\,\mathrm{ms}^{-1} \end{aligned}$$

(c)



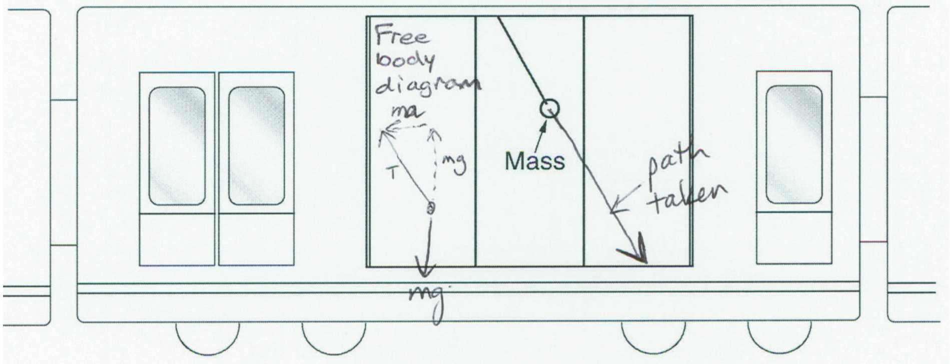
Question 23

(a)

The train is accelerating to the left.

> Note: An acceration to the left is occuring regardless of whether the train is moving to the right and slowing down or moving to the left and speeding up.

(b)



To an observer in the accelerating reference frame of the train the mass will appear to experience a horizontal acceleration equal to the acceration of the train (but in the opposite direction) and a downward vertical acceleration of 9.8 ms^{-2} due to gravity. The ratio of these two accelerations is the same as the ratio of the horizontal and vertical components of the tension in the string, so the path will be parallel to the direction of the string before it was cut.

Question 24

Kepler's law of periods is

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

It can be proved for circular orbits in the case where one body (with mass M) is much more massive than the other body (with mass m) by setting the centripetal force required to keep the smaller body in motion equal to gravitational force between the masses

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

and noting that

$$v = \frac{2\pi r}{T}$$

In the case of the telescope, the required centripetal force is provided by the gravitational attraction of both the earth *and* the sun, meaning that the equation will need to include two gravitational force terms, resulting in a more complicated expression than Kepler's law of periods for this case.

Question 25

(a)

The total momentum of the system consisting of the rocket and the exhaust gases remains constant, so that the change in momentum of the rocket (which is increasing in the vertical direction) is equal and opposite to the change in momentum of the exhaust gases.

(b)

The g-force (the acceleration acting) on the astronauts increases between times t_1 and t_2 as the force is constant but the mass of the rocket is decreasing and

$$a = \frac{F}{m}$$

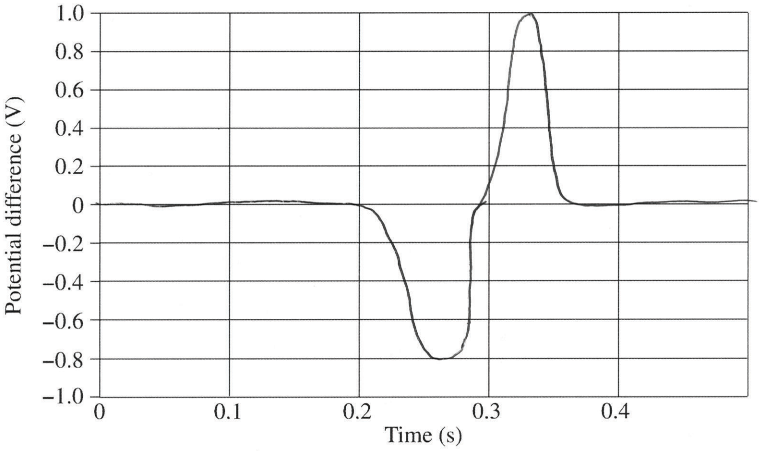
Question 26

(a)

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

As the velocity of the magnet is higher at Y than at X the rate of change of the magnetic flux is higher and so the emf is larger in magnitude.

(b)



Note: For three marks, the graph needs to have a min then a max (as the magnet is dropped south pole downwards), the initial min needs to occur at a later time (as dropped from a greater height) and the time between the two extrema needs to be less (as the magnet is travelling faster).

Question 27

Application	Particle accelerators	Maglev trains
Use of superconductors	Used in superconducting magnets to guide charged particles	Used in superconducting magnets in the train (in EDS system) to induce eddy currents in coils in the track to produce levitation.
Impact on Society	Provides knowledge of the smallest and most exotic particles in the universe fulfilling a human need to understand	Has the potential to provide very fast transport - better transport assists the economy and thus lifts the standard of living
Impact on Environment	Superconducting magnets use a lot of electrical power and there is local disturbance to the environment due to their large size	Local disturbance to the physical environment for new tracks, less noise, use of liquid He (a non-renewable resource) in EDS system
Judgement of impact	Significant impact within the physics community, but insignificant impact on society as a whole, and on the enviroment as a whole	Insignificant impact on society and the environment to date as it has not been widely adopted.

Question 28

The force is

$$\begin{aligned} F &= \Delta m g \\ &= \left(7.5 \times 10^{-4}\,\mathrm{kg}\right) \times \left(9.8\,\mathrm{ms}^{-2}\right) \\ &= 7.35 \times 10^{-3}\,\mathrm{N} \end{aligned}$$

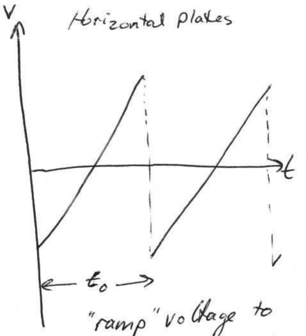
The magnitude of the magnetic field is

$$\begin{aligned} B &= \frac{F}{IL} \\ &= \frac{7.35 \times 10^{-3}\,\mathrm{N}}{(0.3\,\mathrm{A}) \times (0.2\,\mathrm{m})} \\ &= 0.12\,\mathrm{T} \end{aligned}$$

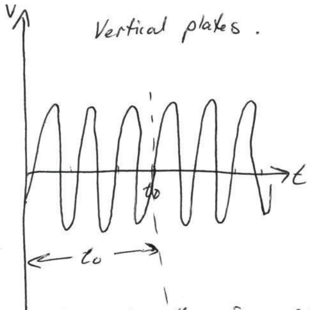
Using the right hand rule, the direction is into the page.

Question 29

Two sets of deflection plates are used. One is used to scan the beam horizontally across the screen at a rate set by the time constant. The other set deflects the electron beam vertically in proportion to the voltage (the signal) applied to the plates. In the case of the pattern displayed on the screen in the question, the voltage applied to the vertical deflection plates varies sinusoidally with time.



"ramp" voltage to move ~~cursor~~ beam from left to right at a const. rate.
t_0 = time constant, which is length of signal shown on screen.



"signal" voltage in eg. given there are 3 λ per time constant t_0

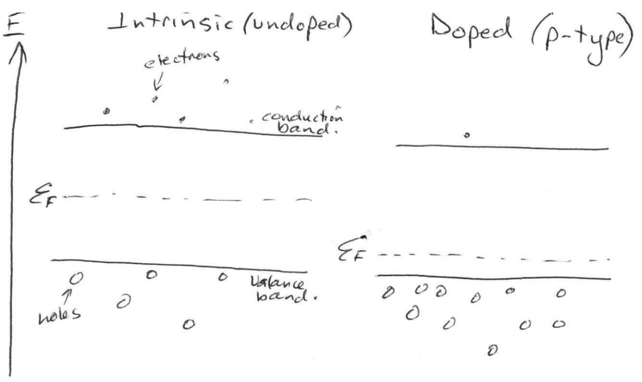
Question 30

(a)

The germanium is p-type as boron is a group III element with one less valance electron than germanium.

(b)

The addition of boron increases the conductivity by significantly increasing the number of holes in the valance band. Thus in p-type germanium the majority charge carriers are holes wheras in intrinsic (undoped) germanium current is carried by equal numbers of electrons in the conduction band and holes in the valance band.



Question 31

(a)

$$\begin{aligned} E &= hf \\ &= \frac{hc}{\lambda} \\ &= \frac{(6.63 \times 10^{-34}\,\text{Js}) \times (3 \times 10^{8}\,\text{ms}^{-1})}{1000 \times 10^{-9}\,\text{m}} \\ &= 1.99 \times 10^{-19}\,\text{J} \end{aligned}$$

(b)

The photoelectric effect is the emission of electrons from a surface in response to incident photons which have energy $E > \Phi$, where Φ is the work function of the material.

As

$$E = hf$$

and

$$c = f\lambda$$

then if

$$\lambda > \frac{hc}{\Phi}$$

there will be no electric current produced in the photocell.

Question 32

The gravitational potential energy of the earth-spacecraft, mars-spacecraft and sun-spacecraft system is the sum of the gravitational potential energy associated with each of the three pairs of masses individually

$$\begin{aligned} E_{P_{tot}} &= E_{P_{ES}} + E_{P_{MS}} + E_{P_{SS}} \\ &= -\frac{GM_E m_S}{r_{ES}} - \frac{GM_M m_S}{r_{MS}} - \frac{GM_S m_S}{r_{SS}} \end{aligned}$$

where M_E, M_M, M_S and m_S are the masses of the Earth, Mars, Sun and the spacecraft, respectively, and where r_{ES}, r_{MS} and r_{SS} are the distances between the centre of the earth, mars, sun and the spacecraft respectively.

As the spacecraft moves outwards from the surface of the Earth its total gravitational energy will increase (as r_{ES} becomes larger), and as the spacecraft moves away from the earth towards Mars it is also moving further away from the sun (r_{SS} also becomes larger) again requiring a substantial increase in its total gravitational energy. During the descent towards the surface of Mars the gravitational energy will decrease (but remain higher than it was on the surface of the earth). The return trip will entail an exact reversal of all these changes in gravitational potential energy.

Some of the required increase in gravitational energy can be obtained by conversion of the boost in kinetic energy gained by launching the spacecraft to the east (taking advantage of the earth's rotational velocity) and in the direction of the earth's orbit around the sun (to take advantage of the earth's orbital velocity).

The remainder must be supplied by conversion of chemical energy stored in the spacecraft itself, which must also supply energy to change the velocity of the spacecraft during takeoff from earth, during the spacecraft's controlled descent into the Martian atmosphere, as well as during any adjustment to its trajectory en route to Mars.

A second significant problem encountered during the trip to Mars is that of protecting the spacecraft from the solar wind. High energy charged particles have the potential to damage human DNA, electronics and other materials in the spacecraft. While it is possible to design electronics to be 'radiation hard', the threat to the astronauts' health posed by ionising radiation is a more difficult problem. One possibility might be to generate a magnetic field around the spacecraft which will result in a force

$$F = qvB \sin\theta$$

which can be used to deflect the high energy charged particles. A limitation of this approach is that very high energy electromagnetic radiation (gamma rays) will not be deflected by the B field (as photons do not carry a charge) and may still pose a threat to astronauts. Potentially, this remaining risk might be mitigated by appropriate sheilding of the spacecraft.