PHYSICS

Unit 3 – Written examination 1

2012 Trial Examination

SOLUTIONS

SECTION A – Core
Motion in one and two dimensions

Question 1

Answer: **120 N**
Explanation: Figure 1 shows that at t = 5 sec, the cart is travelling with constant velocity, so by Newton's First Law, the forces acting on it must be balanced. If the driving force is 120 N, then the drag forces must also total 120 N in the opposite direction.

Question 2

Answer: **0.1 N**
Explanation: Use the gradient of the graph to accurately determine the acceleration

$$a = \frac{\Delta v}{t} = \frac{-5}{6} = -0.83 ms^{-2}$$

Then apply Newton's second law to the 150 g cart: $F = ma = 0.15 \times 0.83 = 0.1N$ (Ignore negative as only magnitude is required. The negative simply indicates that the net force is in the opposite direction to the velocity).

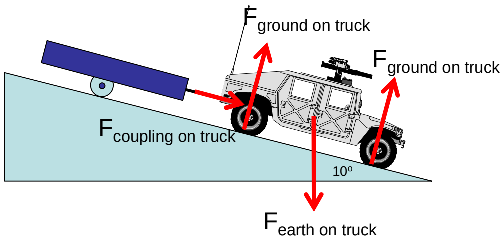
Question 3

Answer: **55 m**
Explanation: Distance covered is equal to the area under the graph:

$$d = 5 \times 8 + 0.5 \times 5 \times 6 = 55m$$

Question 4

Answer: **See diagram below.**
Explanation: Note the compression in the coupling leads to a force acting on the truck down the inclined plane.



Question 5

Answer: **1.4 x 10^4 N**

Explanation: Apply Newton's second law to the 7000 kg truck: $F = ma = 7000 \times 2 = 1.4 \times 10^4\ N$

Question 6

Answer: **8.3 x 10^4 N**

Explanation: Vector addition of all forces acting on the truck:

$$F_{net} = 1.4 \times 10^4\ N = W \sin\theta + F_{coupling} - F_{friction} - F_{brake}$$

$$F_{brake} = 7000 \times 10 \times \sin 10^0 + 4000 - 7000 \times 10 \times 15\% - 1.4 \times 10^4$$

$$F_{brake} = -8345\ N$$

F_{brake} is 8345 N acting up the slope.

Question 7

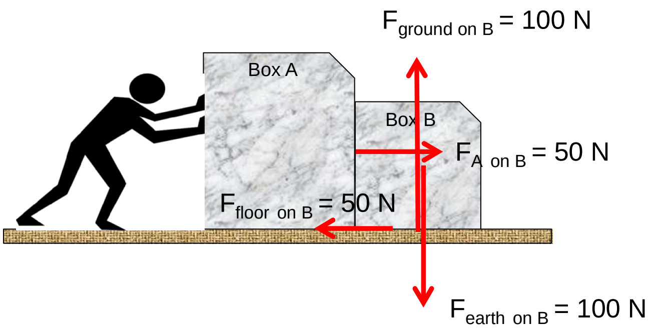
Answer: **150 N**

Explanation: Forces in all directions should be balanced as both Boxes are travelling at a constant speed. Thus: $F_{Ivan\,on\,Box\ A} = 100 + 50 = 150\,N$

Question 8

Answer: **See diagram below.**

Explanation: Forces in all directions should be balanced as Box B is travelling at a constant speed. Thus, vectors should be shown with appropriate matching lengths



Question 9

Answer: **50 N to the left.**

Explanation: According to Newton III, $\boldsymbol{F}_{\text{Box A on Box B}} = -\boldsymbol{F}_{\text{Box B on Box A}}$.

Question 10

Answer: **7.1 ms^{-1}**

Explanation: Use: $v = \frac{2\pi r}{T} = \frac{2\pi \times 3.5}{3.1} = 7.1 ms^{-1}$

Question 11

Answer: **359 N**

Explanation: Use: $F = \frac{mv^2}{r} = \frac{25 \times 7.1^2}{3.5} = 359\,N$

Question 12

Answer: 438 N

Explanation: Use pythagoras to find hypotenuse of triangle with W (vertical) and F_{net} (horizontal) sides. $T = \sqrt{W^2 + F_{net}^2} = 438\,N$

Question 13

Answer: **B, C, D**

Explanation: Increasing the speed of the ride would decrease the period, so A is incorrect. All other options are correct. The net force would increase with the square of the speed, the angle and radius would also increase.

Question 14

Answer: **2 x 10^{5} m**

Explanation: Use Newton's law of Gravitation, remembering that **r** is measured from the centre of mass of each body:

$$F = \frac{GMm}{r^2} = \frac{6.67 \times 10^{-11} \times 2.9 \times 10^{23} \times 7.2 \times 10^3}{\left(R_{Tritonius} + Altitude\right)^2} = 2.06 \times 10^4\,N$$

$$\therefore Altitude = 2 \times 10^5\,m$$

Question 15

Answer: **100 mins**

Explanation: Use Newton's law of Gravitation, rearranged for satellites:

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

$$T = \sqrt{\frac{R^3 \times 4\pi^2}{GM}} = \sqrt{\frac{\left(2.6 \times 10^6\right)^3 \times 4\pi^2}{6.67 \times 10^{-11} \times 2.9 \times 10^{23}}} = 5989\,\text{sec}$$

Question 16

Bill is correct, as the occupants of the orbiter would feel weightless (ie. Experience apparent weightlessness) as the net force on all orbiting material would be constant towards the centre of

Tritonus, as would be the weight force. Unlike when on Earth, there would be no reaction force from the floor of the orbiter pushing on the occupants and they would appear to float around the cabin.

Question 17

Answer: **31 ms^{-1}**
Explanation: Use kinematics equations to find the initial vertical velocity, given $v_{\text{vert}} = 0$ at 1.8 sec after launch:

$$v = u + at$$

$$0 = u - 10\times 1.8$$

$$u = 18\, ms^{-1}$$

Then, use trignometry to determine v at 35^{o}: $v = \dfrac{18}{\cos(55)} = 31.4\, ms^{-1}$

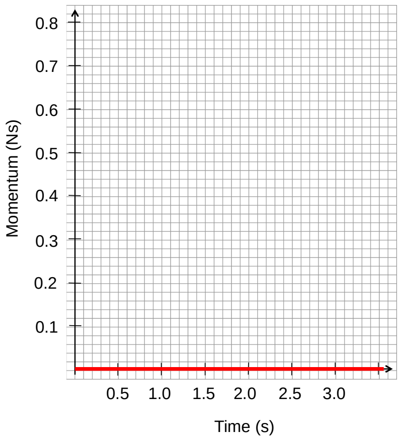
Question 18

Answer: **R = 46 m**
Explanation: $v_{horiz} = v\times\cos(35) = 25.7\, ms^{-1}$

$$x = v_h \times t = 46.26\ m$$

Question 19

See graph below – total momentum is zero as it is effectively an isolated collision with no external forces.



Question 20

Answer: **0.52 J**
Explanation: Isolated collision, so $\boldsymbol{p}_{\text{A}} = -\boldsymbol{p}_{\text{B}}$ after release.

$$v_B = \frac{v_A m_A}{m_B} = \frac{0.35\times 1.3}{0.2} = 2.3\, ms^{-1}$$

$$KE_B = 0.5mv^2$$

$$KE_B = 0.5\times 0.2\times 2.3^2 = 0.51J$$

SECTION A – Core
Electronics and photonics

Question 1

Answer: **3 A**

Explanation: $R_{TOTAL} = \frac{6\times 6}{6+6} = 3\Omega$, $I_{TOTAL} = \frac{V}{R} = \frac{9}{3} = 3A$

Question 2

Answer: **See table**

Parameter	Effect
Current at A	INCREASED
Current at C	UNCHANGED
Current at D	UNCHANGED

Adding another parallel element to the circuit will reduce the overall resistance and thus increase the total current (ie. At A). Because the voltage across the original resistors at C and D remains unchanged (V same in parallel), the current at C and D remains constant.

Question 3

Answer: **6.75 W**
Explanation: Note current through X is equal to total current through pair of 3 Ω resistors near C.

$$I_X = \frac{V}{R} = \frac{9}{6} = 1.5A$$

$$P_X = I^2 R = 6.75W$$

Question 4

Answer: **P_A = 0.18 W, P_B = 0 W**
Explanation: LED B is in reverse bias, so I = 0, P = 0. Calculation for A is more complicated. The current is shared by the 40 Ω resistor and LED A, with the voltage across the 40 Ω resistor fixed as 2.1 V (parallel with LED).

$$V_{LED\,A} = 2.1V$$

$$V_{50} = 9 - 2.1 = 6.9V$$

$$I_{50} = \frac{6.9}{50} = 0.138A$$

$$I_{40} = \frac{2.1}{40} = 0.053A$$

$$I_{LED\,A} = 0.138 - 0.053 = 0.0855A$$

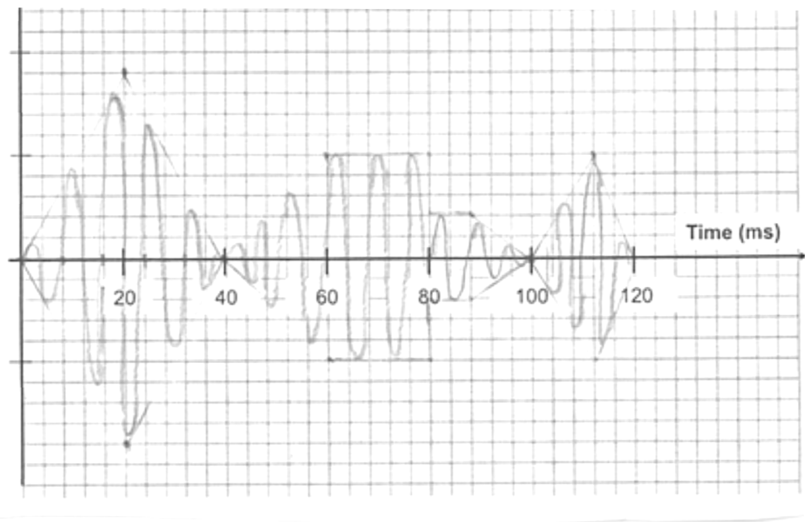
$$P_{LED\,A} = 2.1\times 0.0855 = 0.18W$$

Question 5

If the 50 Ω were replaced with a connection of minimal resistance, LED A would likely burn out. This is because the voltage across the LED would now try to increase to 9 V to match the supply and, according to the standard characteristic curve for an LED, lead to a spike in current (and heat) that would be fatal for the LED.

Question 6

Answer: See diagram below.
Explanation: The modulated signal must retain the frequency of the carrier curve and the amplitude of the initial information signal. Note $t_{carrier} = 0.0008$ s = "2 blocks" on the graph.



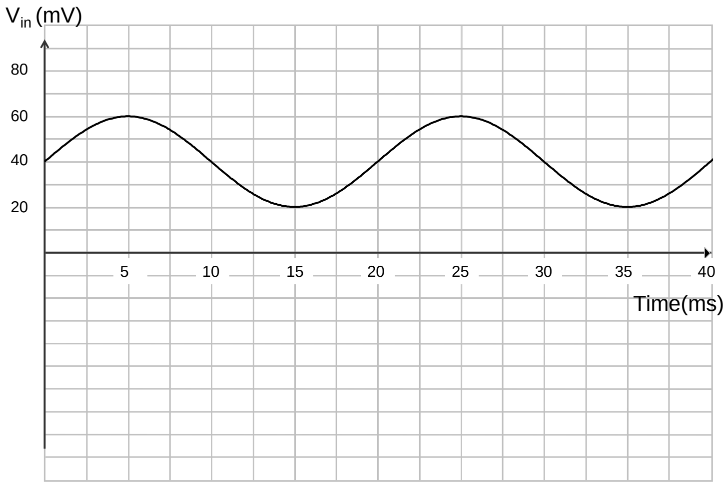
Question 7

Answer: **Gain = 125, inverting**.

Explanation: Magnitude of the amplifier: $Gain = \left|\frac{\Delta V_{out}}{\Delta V_{in}}\right| = \left|\frac{5}{40\times10^{-3}}\right| = 125$

Question 8

Answer: **See diagram.**
Explanation: The output starts at 2 V, which corresponds to V_{in} = 40 mV. Initial increase in V_{in} will lead to clipping beyond V_{in} = 50 mV and will therefore clip at V_{out} = 1 V. In the other direction, an amplitude of 20 mV will lie within the operational linear range of the amplifier, peaking at 4.5 V (some tolerance allowed here).
Note that the output is sketched assuming a initially positive V_{in} – which is subsequently inverted.



Question 9

Answer: **Light: 60 μA Dark: 0 A**
Explanation: The current through the photodiode is equal to the current through the resistor:

$$I = \frac{V}{R} = \frac{9-0.6}{140\times10^{3}} = 6\times10^{-5}\,A$$

Question 10

R must be reduced to achieve the desired effect. Thus, with the same light and same LDR resistance, the voltage across the LDR will be higher than 1 V.

SECTION B – Detailed Studies
Detailed Study 1 – Einstein's Special Relativity

Question 1

Answer: **B**
Explanation:
$$E_K = (\gamma - 1) m_o c^2$$
$$\gamma = \frac{E_K}{m_o c^2} + 1 = 2.6$$
$$\gamma m_o = 2.6 \times 1.67 \times 10^{-27} = 4.34 \times 10^{-27}\, kg$$

Question 2

Answer: **C**
Explanation:
$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = 1.4$$
$$E_K = (\gamma - 1) m_o c^2 = 3.28 \times 10^{-14}\, J$$

Question 3

Answer: **D**
Explanation:
$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = 1.51$$
$$l_o = l\gamma = 4000 \times 1.51 = 6047\, m$$

Question 4

Answer: **D**
Explanation:
$$\Delta E_K = \Delta \gamma m_o c^2$$
$$\Delta \gamma = \frac{\Delta E_K}{m_o c^2} = \frac{6 \times 10^{-11}}{1.67 \times 10^{-27} \times \left(3 \times 10^8\right)^2} = 0.4$$
$$\gamma_i = 1.1$$
$$\gamma_f = 1.1 + 0.4 = 1.5$$

Question 5

Answer: **A**
Explanation: Both messages travel at the speed of light, irrelevant of their source's speed.

Question 6

Answer: **C**
Explanation: Both messages travel at the speed of light, irrelevant of their source's speed. As the destination is 2.6 light years away as measured by a Zephodian observer, the signals would take 2.6 years to arrive.

Question 7

Answer: **B**
Explanation:

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 1.25$$

$$l = \frac{l_o}{\gamma} = \frac{2.6}{1.25} = 2.08\, l.y.$$

Question 8

Answer: **A**
Explanation:

$$t = \frac{d}{v} = \frac{d_0}{\gamma \cdot v} = \frac{2.08}{0.6} = 3.47\, years$$

Question 9

Answer: **B**
Explanation:
Length contracts in the direction of motion, so **b** is affected, but not **a**

Question 10

Answer: **C**
Explanation: By standard definition

Question 11

Answer: **C**
Explanation: Rotation would lead to acceleration and a non-inertial reference frame.

Question 12

Answer: **D**
Explanation: The frequency of the light would not change, but interference effects were intended to demonstrate the existence of the aether.

SECTION B – Detailed Studies
Detailed Study 2 – Materials and their use in structures

Question 1

Answer: **D**
Explanation: Young's modulus is equal to the gradient of the linear elastic section of the stress-strain curve:

$$E = \frac{\sigma}{\varepsilon} = \frac{9\times10^{7}}{2.4\times10^{-3}} = 3.75\times10^{10}\,Pa = 37.5GPa$$

Question 2

Answer: **B**
Explanation: Ultimate tensile strength is equal to the maximum stress recorded prior to fracture – here 100 MPa

Question 3

Answer: **B**
Explanation:

$$\sigma = \frac{F}{A}$$

$$A = \frac{F}{\sigma} = \frac{126\times10^{3}}{40\times10^{6}} = 3.15\times10^{-3}$$

$$d = \sqrt{\frac{4A}{\pi}} = 0.063m = 6.3cm$$

Question 4

Answer: **B**
Explanation: Read from graph, strain = 1.6 x 10^{-3}

$$\Delta L = \varepsilon L = 1.6\times10^{-3}\times2.5 = 4\times10^{-3}\,m$$

Question 5

Answer: **D**
Explanation: Strain energy is equal to area under the stress-strain curve multiplied by the volume of the sample:

$$E = \left(0.5\times60\times10^{6}\times1.6\times10^{-3}\right)\times\left(\frac{\pi\times0.04^{2}}{4}\times2.5\right) = 151J$$

Question 6

Answer: **A**
Explanation: Toughness can be measured as the area under the stress-strain curve

$$\left(0.5\times60\times10^{6}\times1.6\times10^{-3}\right) = 4.8\times10^{4}\,Jm^{-3}$$

Question 7

Answer: **D**
Explanation: Extensive plastic deformation – which follows the initial linear, elastic section of the stress-strain curve, is evidence of ductile behaviour.

Question 8

Answer: **D**
Explanation: The reaction force at B needs to support the weight of the vertical member plus the vertical component of the cable tension.
$R_B = 15 \times 10 + 200 \times \cos(43) = 296\,N$

Question 9

Answer: **C**
Explanation: Rod CD needs to provide a balancing force for the tension in AC. So, it too will be in tension (pulling the vertical member towards the right).
$F_{CD} = 200 \times \sin(43) = 136\,N$

Question 10

Answer: **A**
Explanation: At A, the bolt experiences a pair of forces opposite in direction, but offset slightly. This is shear.

Question 11

Answer: **A**
Explanation: To determine the reaction force at A, we can take the sum of all torques at a simply supported point that is free to rotate, knowing that there must be rotational equilibrium.
$\Sigma \tau_B = 0$
$F_A \times 7 + 2000 \times 10 \times 2 = 4000 \times 10 \times 4.5 + 2000 \times 10 \times 1$
$F_A = 22857\,N = 22.9\,kN$

Question 12

Answer: **C**
Explanation: It is important to recognise that FB is also directed upwards (246 kN) and thus the beam will deflect with tension at the base of the beam between A and B and tension across the top of the beam between B and the free end.
The steel reinforcement provides additional strength to the beam in areas of tension.

SECTION B – Detailed Studies
Detailed Study 3 – Further Electronics

Question 1

Answer: **D**
Explanation: $V_{peak} = \sqrt{2} \times V_{RMS}$, plus the voltage is then stepped up by the transformer.
$V_{peak} = \left(3 \times \sqrt{2}\right) \times 3 = 12.7V$

Question 2

Answer: **A**
Explanation: $\tau = RC = 4000 \times 100 \times 100^{-6} = 0.4\,s$

Question 3

Answer: **B**
Explanation: Without the smoothing effect of the capacitor, the diode trims 0.7 V from the peak voltage and also removes any negative voltage. The period of the supply voltage remains at 20 ms.

Question 4

Answer: **D**
Explanation: With a time constant of 0.4 s, which is 20 times the period of the supply, one would expect extensive smoothing, again with a peak of 12 V.

Question 5

Answer: **C**
Explanation: A 4 kΩ load will give a current of approximately 2 mA based on the 9 V RMS stepped up supply. This equates to ~ 20 mW, which will be the same on both primary and secondary sides of the transformer.

Question 6

Answer: **C**
Explanation: The resistor must ensure that a min of 1.7 mA (from graph) runs through the Zener diode to ensure it operates at the 4 V avalanche point.
$R = \frac{V}{I} = \frac{1}{1.7 \times 10^{-3}} = 588\Omega$. The closest option is thus C.

Question 7

Answer: **D**
Explanation: $V_{\max} = 2 \times \sqrt{2} \times 2 - 1.4 = 4.24V$

Question 8

Answer: **D**
Explanation: To reduce the ripple voltage, the time constant must be increased: increase C, R.

Question 9

Answer: **C**
Explanation: The short time constant of the circuit and low V_{max} means that the voltage will quickly drop below the 4 V (absolute min) required by the zener diode.

Question 10

Answer: **B**
Explanation: When the switch is moved to A, the voltage across the resistor will initially be 24 V and decrease as the voltage across the capacitor increases. With a time constant of $\tau = RC = 10\times10^{3}\times200\times10^{-6} = 2\,\text{sec}$, it will take 2 sec for the capacitor to charge 63% of 24 V = 15 V. So R will be equal to 9 V after approx. 2 sec.

Question 11

Answer: **C**
Explanation: When the switch is moved to B, the voltage across the resistor will initially be 24 V and decrease as the voltage across the capacitor increases. With a time constant of $\tau = RC = 5\times10^{3}\times200\times10^{-6} = 1\,\text{sec}$, it will take 5τ for the capacitor to fully discharge. So R will be return to 0 V after approx. 5 sec.

Question 12

Answer: **A**
Explanation: The discharging process of the capacitor begins rapidly, then more slowly towards the end. Thus the resistor will experiene a rapid decrease in voltage for the first 3 seconds.

