QCAA ALTERNATIVE SEQUENCE PHYSICS EXTERNAL EXAM – 2023

MULTIPLE CHOICE QUESTIONS - SOLUTIONS AND EXPLANATIONS

Dr Richard Walding, richard@walding.com

Percentages (%) will indicate the overall choice by students (QCAA Subject Report 2024)

Q		%	Reasoning
1	A	3.79	Incorrect. Length contraction changes the length in the direction of travel.
	B	24.42	Incorrect. As the velocity of an object increases the amount of time dilation also increases. That is, clocks aboard the moving object would appear to slow and as the object approached *c*, the clocks would slow to a standstill. This does not mean the velocity of the object would also slow, only their clocks. That would not prevent the object from attaining a speed of *c*.
	C*	59.79	Correct. Relativistic momentum approaches infinity as the speed approaches *c*. The formula $p_v = \frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}$ shows that as v increases to c, the term below the line decreases to zero thus making p_v infinite.
	D	11.37	Incorrect. The inertia (its mass) will not change with increasing speed. The statement that inertia will decrease would mean that less and less force is required to keep accelerating an object and thus it would not be impossible to reach a speed of *c*.
2	A	11.37	Incorrect. They need to maintain zero acceleration to be running at constant velocity. The question says *non-zero* acceleration so their velocity would be changing.
	B*	82.11	Correct. The force of the wind would result in a net retarding force opposing motion. They would need to apply an equal and opposite force to return to a net force of zero and hence zero acceleration.
	C	5.05	Incorrect. The work done on them is the energy imparted on their body by the wind. This is outside of their control if they are at constant velocity and the wind speed is not changing. The drag force of the wind depends on the speed of the object relative to the wind and the faster they go the greater the drag. Similarly, the slower they go the less the drag force. So, to reduce the drag force energy imparted to them they would have to run slower. This is not what is wanted, so the option is incorrect.
	D	1.05	Incorrect. Momentum is the product of mass and velocity ($p = mv$). To reduce momentum you could reduce velocity, but this is the opposite of what the question asks, so is not correct. Alternatively, you could reduce mass. But how? Possibly by taking off your shoes. This is valid but is not the best answer, so this option is incorrect.
3	A*	83.37	Correct. Four half-lives as shown by this progression from 16 g to 1 g in four steps: $$16 \underset{1}{\rightarrow} 8 \underset{2}{\rightarrow} 4 \underset{3}{\rightarrow} 2 \underset{4}{\rightarrow} 1$$ Alternatively: $$N = N_0(\tfrac{1}{2})^n$$ $$1 = 16(\tfrac{1}{2})^n$$

			$$log_{10}\left(\frac{1}{16}\right) = n \times log_{10}\left(\frac{1}{2}\right)$$ $$n = \frac{-1.2}{-0.3} = 4 \text{ half lives}$$
	B	3.58	Incorrect. There are 5 different amounts of nuclides but only 4 steps.
	C	5.89	Incorrect. There are 5 different amounts of nuclides but not 6 steps.
	D	6.74	Incorrect. Used ½ × 16 = 8
4	A	13.26	Incorrect. This is a part of (Kepler's) first law of planetary motion.
	B	11.37	Incorrect. This is describing the idea that objects tend to move in a straight line (Nowton's first law) but when undergoing circular motion, the object needs a force to pull it towards the centre of the circle. This is not (Kepler's) third law of planetary motion.
	C	19.58	Incorrect. This is (Kepler's) second law of planetary motion.
	D*	54.95	Correct. It equates the gravitational force F_g between objects as described by the Law of Universal Gravitation, $F_g = \frac{GMm}{r^2}$, and the force needed to make an object travel in a circle, $F_c = \frac{mv^2}{r}$.
5	A	6.11	Incorrect. This is a description of *nuclear fusion.*
	B	21.89	Incorrect. Electrons are not products of nuclear fission. However, the products of fission often undergo beta negative decay, which is the production of electrons, but this is not in the fission reaction itself. Electrons can be captured by certain nuclei and they cause a proton to turn into a neutron and emit a neutrino.
	C*	43.58	Correct. This is a feature of nuclear fission.
	D	27.79	Incorrect. This is the radioactive decay of a nuclide, not fission.
6	A	22.11	Incorrect. Used 160 m as the distance travelled in the 25 s.
	B*	45.89	Correct. The object moves in a circular motion from Y to Z, half the circumference of a circle: $s = 2\pi r/2 = (2 \times \pi \times 80)/2 = 251$ m. Velocity is $v = s/t = 250/25 = 10.1$ m s^{-1}. Centripetal force: $F_c = \frac{mv^2}{r} = \frac{6.0 \times 10^2 \times 10.1^2}{80} = 7.6 \times 10^2$ N.
	C	20.84	Incorrect. Used 160 m for the radius, not 80 m.
	D	9.89	Incorrect. Did not square the velocity.
7	A	16.63	Incorrect. There is no change in mass as the products are identical to the reactants. However, mass is not always conserved, for example there is often a mass defect in nuclear reactions ($\Delta E = \Delta mc^2$). **A comment for teachers:** Another possible outcome of an electron and positron annihilation is a pair of photons (zero mass), or if they have enough kinetic energy, some heavier particle such as a Z^0 or some meson. The proposed International Linear Collider would use electron-positron collisions to produce Higgs bosons, H^0, with a rest mass around 125,000 times more than the mass of the incoming particles.

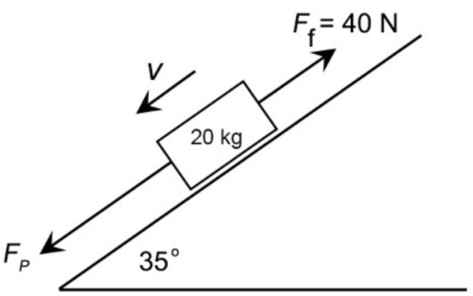
			This process in the question is just one of the Feynman diagrams in the syllabus of electron-positron scattering, along with a virtual exchange of a photon with no annihilation, but there can also be many other (non-syllabus) higher order diagrams. The photon is purely virtual, and nothing really 'annihilates', since two particles come in and two particles go out. The question says, 'producing another electron and positron pair in the process' and this suggests that there is some point where the photon, electron, and positron, all exist at the same time. But that isn't the case – the photon is only 'virtual', and it annihilates back into the electron-positron pair. The only measurable outcome is that the electron and positron have exchanged some kinetic energy and momentum. In summary, this option is correct.
	B	10.32	Incorrect. Baryons are quark composites and there are no quarks or baryons mentioned in the interaction.
	C*	65.26	Correct. Lepton number is always conserved in a particle interaction. In this case the lepton number L = 0 at the start $({}^{+}1 + {}^{-}1 = 0)$ and L = 0 at the end $({}^{+}1 + {}^{-}1)$.
	D	7.37	Incorrect. There are two particles to start with and two at the end. The photons produced in the interaction are virtual photons and are not released into the surroundings. They
8	A	16.0	Incorrect. Most likely calculated *u* correctly but said the velocity of the two coupled objects would be $2u$.
	B*	46.11	Correct. $p_i = p_f$ $m(u + 40) + mu = 2m(3u)$ $m(2u + 40) = 2m(3u)$ $2u + 40 = 6u$ $u = +10 \text{ m s}^{-1}$ $v_Z = 3u$ $= 30 \text{ m s}^{-1}$
	C	23.16	Incorrect. Two mistakes. Solution uses the final mass as *m* instead of 2*m* and just calculates *u* not 3*u*. $p_i = p_f$ $m(u + 40) + mu = m(3u)$ $m(2u + 40) = m(3u)$ $2u + 40 = 3u$ $u = +40 \text{ m s}^{-1}$
	D	13.47	Incorrect.
9	A	5.89	Incorrect. Ignored the negative sign in front of 1.3: $s = (1.3 \pm 0.2) \times 7^2 + 203 \pm 2$ $s = 63.7 \pm 9.8 + 203 \pm 2$ $s = 266.7 \pm 11.8$ $s_{max} = 278.5 \text{ m}$ $s_{min} = 254.9 \text{ m}$

	B	5.05	Incorrect. Didn't square the *t*, and left out the negative sign on –1.3. $s = (1.3 \pm 0.2) \times 7 + 203 \pm 2$ $s = 9.1 \pm 1.4 + 203 \pm 2$ $s = 212.1 \pm 3.4$ $s_{max} = 215.5$ m $s_{min} = 208.7$ m
	C	8.63	Incorrect. Didn't square the *t*. $s = (-1.3 \pm 0.2) \times 7 + 203 \pm 2$ $s = -9.1 \pm 1.4 + 203 \pm 2$ $s = 193.9 \pm 3.4$ $s_{max} = 197.3$ m $s_{min} = 190.5$ m
	D*	79.79	Correct. The value must be between 127.5 and 151.1 m. $s = (-1.3 \pm 0.2) \times 7^2 + 203 \pm 2$ $s = -63.7 \pm 9.8 + 203 \pm 2$ $s = 139.7 \pm 11.8$ $s_{max} = 151.2$ m $s_{min} = 127.5$ m Note: the question wrongly uses 'deceleration' to mean 'negative acceleration'. The object in this case is accelerating (probably down an incline) in the negative direction. It is speeding up therefore it is not 'decelerating'.
10	A*	34.95	**Note: This question was identified by QCAA as being outside the scope of AS Unit 1 and Unit 2, so all students were awarded a 1 mark for this question.** Correct. $\lambda = \frac{b}{T} = \frac{2.898 \times 10^{-3}}{6040} = 4.798 \times 10^{-7}$m $f = \frac{c}{\lambda} = \frac{3 \times 10^{8}}{4.798 \times 10^{-7}} = 6.3 \times 10^{14}$ Hz **A comment for teachers.** The answer above uses Wien's law which gives the maximum of the spectral distribution of blackbody radiation parametrized by wavelength. However, the question is about the frequency of the maximum not the wavelength. In the solution above the maximum wavelength is determined and then converted to frequency using $f = c/\lambda$. The problem is that the shape of this distribution is very different if you plot it as a function of wavelength compared to plotting it as a function of frequency. In particular, the location of the peak is different. The frequency of maximum energy density is obtained by locating the maxima of the Planck distribution with respect to frequency is a different formula: $f_{peak} = 5.8789 \times 10^{10} \times T = 3.55 \times 10^{14}$ Hz

			- which is not one of the options. The other feature of the question is that it asks for the "frequency <u>at which the maximum number of photons is produced</u>." The issue here is that each photon has energy *hf*, so the number of photons is proportional to the energy density divided by *f*. The answer to this is different to the answer using either Wien's law of the frequency formula above. Asking for the 'maximum number of photons' is an additional complication requiring some calculus. Well, that would be fun. Note: This question is not relevant to Unit 1/2 syllabus for AS Physics. It is part of quantum theory which is Unit 4.
	B	27.37	Incorrect. Used formula as: $\lambda = bT$ $= 2.898 \times 10^{-3} \times 6040 = 2.1 \times 10^{6}$
	C	22.95	Incorrect. This is the wavelength in metres, not the frequency in Hz.
	D	12.63	Incorrect. Had frequency formula upside down: $f = \frac{\lambda}{c} = \frac{4.798 \times 10^{-7}}{3 \times 10^{8}} = 1.6 \times 10^{-15}$
11	A	37.26	Incorrect. Atoms are held together by various forces mainly electrostatic in origin. The strong nuclear force operates between nucleons (Unit 1) and between quarks (Unit 4).
	B	7.37	Incorrect. It varies with the separation distance so is not constant.
	C*	39.79	Correct. This is a characteristic of the strong nuclear force. See OUP *Physics* U1&2 page 148.
	D	15.16	Incorrect. This is the electromagnetic force.
12	A*	36.42	Correct. In all particle interactions momentum is conserved. This must occur when a symmetry operation is performed.
	B	14.95	Incorrect. Only in some symmetry operations are charges different. They don't necessarily have to be.
	C	36.0	Incorrect. Antiparticles are shown with their arrow pointing in the opposite direction to time, but this is not a consequence of symmetry but just a convention.
	D	12.0	Incorrect. Mass could be converted to energy, but it doesn't have to be such that the mass of products is less than the mass of reactants.
13	A*	19.58	Correct. Fusion requires two or more light nuclei to fuse together to form one or more different, heavier, atomic nuclei and subatomic particles. For lighter nuclei, below Fe-56, there will be a loss in mass and a release of energy to produce a nuclide that is more stable and has more binding energy. This reaction appears to meet these two criteria and is by far the best of the four options. **A comment for teachers.** Fusion reactions with reactants having an initial mass of 5.02 amu include: ${}^{3}_{2}\text{He} + {}^{2}_{1}\text{H}$ (3.016 + 2.014 = 5.03 amu) or ${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H}$ (2.014 + 3.016 = 5.03 amu). However, it is difficult (impossible) to find products with a mass of 4.98 amu as most nuclides have a mass in multiples of 1.0 amu and over. Students are not provided with tables of nuclide masses in the exam and thus this is irrelevant. This question is clear it is about the total mass of reactants and products and not individual masses. Furthermore, the question is hypothetical and not

			necessarily practical, so the option remains correct. Remember that **the best answer should be selected** not the one that could have some validity.
	B	19.16	Incorrect. Fusion requires two light nuclei to fuse together, and in this case the total mass is 5.02 amu so they can be considered light. However, reactions involving nuclides up to about Fe-56 release energy so the mass of products will be less than reactants. In this case the mass of the products (10.08 amu) is greater than that of the reactants (10.05 amu). This option doesn't meet that criterion, so it is incorrect. **A comment for teachers:** There may be rare cases where light nuclei can fuse without releasing energy, so it may have some validity but is not the best option.
	C	26.11	Incorrect. Fusion requires two light nuclei to fuse together, that is, with a mass less than Fe-56. This option has nuclei with a total mass of 235 amu, and so only fission could occur. There may be rare cases where heavy nuclei can fuse, so it may have some validity but is not the best option.
	D	33.89	Incorrect. Fusion requires two light nuclei to fuse together, that is, with a mass less than Fe-56. This option has nuclei with a total mass of 236 amu, and so only fission could occur. There may be rare cases where heavy nuclei can fuse, so it may have some validity but is not the best option.
14	A	27.16	Incorrect. It is a lepton but has same mass as a positron.
	B	14.53	Incorrect. Is not a baryon but does have smaller mass than a proton.
	C	8.63	Incorrect. Is not a meson and does not experience the strong nuclear force.
	D*	49.26	Correct. Is electrically charged so interactions mediated by the electromagnetic force whose particles are photons.
15	A	14.32	Incorrect. Mass was not doubled.
	B*	44.42	Correct. Doubling the distance decreases the force by ¼. Increasing the mass of one object doubles the force. Result: $(\frac{1}{4} \times 2)F = \frac{1}{2}F$
	C	29.47	Incorrect. $(2 \times r)$ not squared so force only halved due to doubling distance.
	D	10.95	Incorrect. Says doubling the distance increases force by 4 and says that doubling the mass decreases force by 2. Result (4/2) $F = 2F$.
16	A	13.89	Incorrect. To a stationary observer at the tunnel, the train is less than 95 m so would not see both ends of the train at both ends of the tunnel at the same time. See Option D.
	B	1.47	Incorrect. Mass is invariant (not changing), thus there is no change in mass at any place.
	C	5.89	Incorrect. There is no mention of the train changing speed. The question just says 'relativistic speed' and this is common (same value) to both observers.
	D*	77.89	Correct. The (first) observer on the train is at rest (stationary) to the train so measures the length of the train to be the proper length: L_0 (train) = 95 m. The same observer on the train is moving relative to the tunnel so measures the relativistic (contracted) length of the tunnel: L (tunnel) = 95 m. The second observer is stationary relative to the tunnel so measures the proper length of the tunnel: L_0 (tunnel), but observes the train to be moving, so would measure the relativistic (contracted) length of the train: L (train). If the proper length of the train is 95 m, the second observer would measure this length contracted and thus shorter than 95 m. The second observer knows the proper length of

<table>
<tr><td></td><td></td><td></td><td>the tunnel is 95 m, so the train, which appears shorter than 95 m, is thus shorter than the tunnel. Here is an example if the speed was 0.8 c.

<table>
<tr><td></td><td>1st observer on train</td><td>2nd observer at tunnel</td></tr>
<tr><td>Velocity</td><td>v = 0.8 c</td><td>v = 0.8 c</td></tr>
<tr><td>Train</td><td>L_0 (train) = 95 m</td><td>L (train) = 76 m (< 95 m)</td></tr>
<tr><td>Tunnel</td><td>L (tunnel) = 95 m</td><td>L_0 (tunnel) = 120 m (> 95 m)</td></tr>
</table></td></tr>
<tr><td>17</td><td>A</td><td>22.11</td><td>Incorrect. The particle has to be stationary in its own frame of reference (by definition). It is moving relative to the detector’s frame of reference.</td></tr>
<tr><td></td><td>B</td><td>4.84</td><td>Incorrect. The particle is moving relative to the detector so is moving relative to the detector’s frame of reference.</td></tr>
<tr><td></td><td>C*</td><td>67.37</td><td>Correct. The time of an event is longer (dilated) if the event occurs in a frame of reference moving relative to the observer. The detector sees the particle as moving so measures time in the particle’s frame as being dilated (longer).</td></tr>
<tr><td></td><td>D</td><td>5.26</td><td>Incorrect. The detector signals the detection of the particle irrespective of its speed. If the particle strikes the detector it is ‘present’; if it has already decayed it will not strike the detector.</td></tr>
<tr><td>18</td><td>A*</td><td>58.53</td><td>Correct.


$F_p = mg\sin\theta = 20 \times 9.8 \times \sin 35° = 112\text{ N}$
$F_{net} = 112 - 40 = 72\text{ N}$
$a = \frac{F_{net}}{m} = \frac{72}{20} = 3.6\text{ m s}^{-2}$</td></tr>
<tr><td></td><td>B</td><td>21.89</td><td>Incorrect. Did not subtract friction.</td></tr>
<tr><td></td><td>C</td><td>10.11</td><td>Incorrect. Used cosθ instead of sinθ</td></tr>
<tr><td></td><td>D</td><td>8.21</td><td>Incorrect. Added the forces instead of subtracting them.</td></tr>
<tr><td>19</td><td>A</td><td>20.63</td><td>Incorrect. Didn’t convert mass in amu to kg:
$\Delta E = \Delta mc^2 = 0.0052 \times (3 \times 10^8)^2 = 4.7 \times 10^{14}\text{ J}$</td></tr>
<tr><td></td><td>B*</td><td>45.89</td><td>Correct.</td></tr>
</table>

			$= 7.8 \times 10^{-13}$ J
	C	22.53	Incorrect. Didn't square c. $\Delta m = 0.0052$ amu $= 0.0052\ amu \times 1.66 \times 10^{-27}$ $= 8.632 \times 10^{-30}$ kg $\Delta E = \Delta mc^2$ $= 8.632 \times 10^{-30} \times 3 \times 10^8$ $= 2.6 \times 10^{-21}$ J
	D	10.32	Incorrect. Didn't convert mass in *kg* to energy in *J* (didn't use $\Delta E = \Delta mc^2$): $\Delta m = 0.0052$ amu $= 0.0052\ amu \times 1.66 \times 10^{-27}$ kg/amu $= 8.632 \times 10^{-30}$ kg
20	A	16.84	Incorrect. Used the change in potential energy (1.6 – 0.3 = 1.3 J), and didn't rearrange the 0.6kg correctly. $\Delta E_p = \Delta E_k$ $\Delta E_p = \frac{1}{2}mv^2$ $1.6 - 0.3 = \frac{1}{2} \times 0.6 \times v^2$ $v = \sqrt{1.3 \times 2 \times 0.6}$ $= 1.2$ m s^{-1}
	B	28.84	Incorrect. Just used the maximum value of potential energy as the maximum velocity.
	C*	44.42	Correct. $\Delta E_p = \Delta E_k$ $\Delta E_p = \frac{1}{2}mv^2$ $1.6 = \frac{1}{2} \times 0.6 \times v^2$ $v = \sqrt{\frac{1.6 \times 2}{0.6}}$ $= 2.3$ m s^{-1}
	D	8.42	Incorrect. Didn't take the square root to get *v*. $1.6 = \frac{1}{2} \times 0.6 \times v^2$ $v = \frac{1.6 \times 2}{0.6}$ $= 5.3$ m s^{-1}

Whew! For other worked solutions to EA past papers see seniorphysics.com/ncpq