Part 1 Wind power

(a) Outline in terms of energy changes how electrical energy is obtained from the energy of wind. [2]

- kinetic energy of wind transferred to (rotational) kinetic energy of turbine/blades;

- kinetic energy changed to electrical energy in generator/dynamo

   *Generator/dynamo must be mentioned.*
(i) Deduce that the kinetic energy per unit time of the air incident on the turbine is \[ \frac{1}{2} \pi \rho r^2 v^3 \] [3]

- Volume of cylinder of air passing through blades per second = \( v \pi r^2 \)
- Mass of air incident per second = \( \rho v \pi r^2 \)
- Kinetic energy \( \frac{1}{2} m v^2 \)
- Power = kinetic energy per second = \( \frac{1}{2} m v^2 \) per second = \( \frac{1}{2} (m \text{ per second}) v^2 \)

\[ \text{power} = \frac{1}{2} \pi \rho r^2 v^3 \]

Award [3] for answers that combine one or more steps.

\((BTR: \text{The underlying assumption of this calculation is that the wind is stopped by the wind turbine, which is not the case, so not all of this energy is turned into electricity. The maximum theoretical percentage of the wind’s energy that can be extracted using a turbine is 59%})\)
(ii) State two reasons why it is impossible to convert all the available energy of the wind to electrical energy.

- the speed of the air/wind cannot drop to zero
- wind turbulence / frictional losses in turbine/any moving part / resistive heating in wires;
Air is incident normally on a wind turbine and passes through the turbine blades without changing direction. The following data are available:

- Density of air entering turbine = 1.1 kg m$^{-3}$
- Density of air leaving turbine = 2.2 kg m$^{-3}$
- Speed of air entering turbine = 9.8 m s$^{-1}$
- Speed of air leaving turbine = 4.6 m s$^{-1}$
- Blade length = 25 m

Determine the power extracted from the air by the turbine. [3]

- Kinetic energy per second of air entering turbine:
  \[ \frac{1}{2} \pi \rho r^2 v^3 = \frac{1}{2} \pi \times 1.1 \times 25^2 \times 9.8^3 = 1.016 \times 10^6 \]

- Kinetic energy per second of air leaving turbine:
  \[ \frac{1}{2} \pi \rho r^2 v^3 = \frac{1}{2} \pi \times 2.2 \times 25^2 \times 4.6^3 = 2.102 \times 10^5 \]

- Power extracted:
  \[ = 1.0 \times 10^6 - 2.1 \times 10^5 = 8.062 \times 10^5 \approx 8.1 \times 10^5 \text{ W} \]
(d) A different wind turbine has a mechanical input power of $3.0 \times 10^5$ W and generates an electrical power output of $1.0 \times 10^5$ W. On the grid below, construct and label a Sankey diagram for this wind turbine.

- correct shape of diagram
  (allow multiple arrows if power loss split into different components);
- relative width of arrows correct;
- labels correct;
(e) Outline one advantage and one disadvantage of using wind turbines to generate electrical energy, as compared to using fossil fuels. [2]

**Advantage**
- Wind is renewable so no resources used up / wind is free / no chemical pollution
- No carbon dioxide emission / does not contribute to greenhouse effect
- Is “scalable” i.e. many sizes of turbine possible;

**Disadvantage:**
- Expensive initial cost / large land area needed / wind not constant
- Effect on movement of birds / aesthetically unpleasant
- Noise pollution / high maintenance costs
- Best locations far from population centres
- Low energy density;

*Accept any other suitable advantage or disadvantage.*
Part 2 Radioactive decay

(a) Describe the phenomenon of natural radioactive decay. [3]

- emission of (alpha/beta/gamma) particles/photons/electromagnetic radiation
- nucleus becomes more (energetically) stable
- constant probability of decay (per unit time)
- is random process
- activity/number of unstable nuclei in sample reduces by half over constant time intervals/exponentially
- not affected by temperature/environment / is spontaneous process [3 max]

(b) A nucleus of americium-241 (Am-241) decays into a nucleus of neptunium-237 (Np-237) in the following reaction.

\[ ^{241}_{95}\text{Am} \rightarrow ^{237}_{X}\text{Np} + ^{4}_{2}\alpha \]

(i) State the value of \( X \). [1]

\( 93 \)
(ii) Explain in terms of mass why energy is released in the reaction in (b). [2]

- mass of products is less than mass of reactants / there is a mass defect
- mass is converted into energy (according to equation $E = mc^2$)

(iii) Define binding energy of a nucleus. [1]

- the (minimum) energy required to (completely) separate the nucleons in a nucleus

or

- the energy released when a nucleus is assembled from its constituent nucleons
(iv) The following data are available.

Determine the energy released in the reaction in (b).

- Calculation of binding energies as shown below:
  - Americium-241 = 241 \times 7.54 = 1817.14 \text{ MeV}
  - Neptunium-237 = 237 \times 7.58 = 1796.46 \text{ MeV}
  - Helium-4 = 4 \times 7.07 = 28.28 \text{ MeV}

- Energy released is the difference of binding energies

- And so equals 7.60 \text{ MeV}

Award [2 max] for an answer that multiplies by the number of neutrons or number of protons.

Ignore any negative sign in answer
B1. This question is in two parts. Part 1 is about simple harmonic motion (SHM) and a wave in a string. Part 2 is about the unified atomic mass unit and a nuclear reaction.

Part 1 Simple harmonic motion and a wave in a string

(a) By reference to simple harmonic motion, state what is meant by amplitude. [1]

- the maximum displacement of the system from equilibrium / from centre of motion / OWTTE;
(b) A liquid is contained in a U-tube.

The pressure on the liquid in one side of the tube is increased so that the liquid is displaced as shown in diagram 2. When the pressure is suddenly released the liquid oscillates. The damping of the oscillations is small.

(i) Describe what is meant by damping. [2]

- the amplitude of the oscillations/(total) energy decreases (with time);
- because a force always opposes direction of motion
  / there is a resistive force
  / there is a friction force; [2]

*Do not allow bald “friction”.*
(ii) The displacement of the liquid surface from its equilibrium position is \( x \). The acceleration \( a \) of the liquid in the tube is given by the expression

\[
a = -\frac{2g}{\ell} x
\]

where \( g \) is the acceleration of free fall and \( \ell \) is the total length of the liquid column. The total length of the liquid column in the tube is 0.32 m. Determine the period of oscillation.

\[
\omega^2 = \frac{2g}{\ell} \quad \text{(from definition of SHM: } a = -\omega^2 x)\]

\[
\omega = 2\pi f = \frac{2\pi}{T} \quad \rightarrow \quad T = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{\ell}{2g}} = 2\pi \sqrt{\frac{0.32}{2 \times 9.81}} =
\]

\[
T = 0.80 \text{ s}
\]
(c) A wave is travelling along a string. The string can be modelled as a single line of particles and each particle executes simple harmonic motion. The period of oscillation of the particles is 0.80 s.

The graph shows the displacement $y$ of part of the string at time $t = 0$. The distance along the string is $d$.

(i) On the graph, draw an arrow to show the direction of motion of particle $P$ at the point marked on the string.

upwards;
(ii) Determine the magnitude of the velocity of particle P.

\[ v = \omega \sqrt{y_0^2 - y^2} \] (up positive) \hspace{1cm} (from \( v = \pm \omega \sqrt{x_0^2 - x^2} \))

\[ y_0 = 0.05 \text{ m} \hspace{1cm} y = 0.03 \text{ m} \] (at point P)

\[ \omega = \frac{2\pi}{0.80} = 7.85 \text{ rad s}^{-1} \]

\[ v = 7.85\sqrt{0.05^2 - 0.03^2} \]

\[ v = 0.31 \text{ m s}^{-1} \] (Allow working in cm to give 31 cm s\(^{-1}\))

(iii) Show that the speed of the wave is 5.0 m s\(^{-1}\). \hspace{1cm} [3]

\[ \lambda = 4.0 \text{ m} \]

\[ f = \frac{1}{T} = 1.25 \text{ Hz} \]

\[ v = \lambda f = 4.0 \times 1.25 \]

\[ v = 5.0 \text{ m s}^{-1} \]
(iv) On the graph opposite, label with the letter X the position of particle P at \( t = 0.40 \) s.  

- at \( P \) \( y = 0.03 \) m
- particle at point \( P \) will move up and then down undergoing SHM
- in time 0.40 s \( \left( \frac{1}{2} \text{ of period} \right) \) will cover 10 cm (the full cycle is 20 cm)
- it will go up 2 cm then down 8 cm
- so at \( t = 0.40 \) s, the particle will be at position: \( d = 0.6 \) m, \( y = -3.0 \) cm
Part 2 Unified atomic mass unit and a nuclear reaction

(a) Define the term unified atomic mass unit. [1]

- $\frac{1}{12}$ th mass of an atom of carbon-12

(b) The mass of a nucleus of rutherfordium-254 is 254.1001 u. Calculate the mass in GeV c$^{-2}$. [1]

1 u of mass converts into 931.5 MeV
due to relationship $E = mc^2 \rightarrow 1\ u = 931.5\ MeV\ c^2$

- $m = 254.1001 \times 931.5\ MeV\ c^2 = 236.7 \times 10^3\ MeV\ c^2 = 236.7\ GeVc^{-2}$

(only accept answer in GeV c$^{-2}$)

(c) In 1919, Rutherford produced the first artificial nuclear transmutation by bombarding nitrogen with $\alpha$-particles. The reaction is represented by the following equation.

$\alpha + ^{14}_7N \rightarrow ^{17}_8O + X$

(i) Identify X. [1]

$\frac{4}{2}He + ^{14}_7N \rightarrow ^{17}_8O + X \rightarrow \frac{1}{1}X$

- proton / hydrogen nucleus / H$^+$/\textsubscript{1}$H$
(ii) The following data are available for the reaction.

\[
\begin{align*}
\text{Rest mass of } \alpha & = 3.7428 \text{ GeV } c^{-2} \\
\text{Rest mass of } {^{14}_7N} & = 13.0942 \text{ GeV } c^{-2} \\
\text{Rest mass of } {^{17}_8O} + X & = 16.8383 \text{ GeV } c^{-2}
\end{align*}
\]

The initial kinetic energy of the \( \alpha \) particle is 7.68 MeV. Determine the sum of the kinetic energies of the oxygen nucleus and \( X \). (Assume that the nitrogen nucleus is stationary.)

\[
\alpha + {^{14}_7N} \rightarrow {^{17}_8O} + X
\]

Rest mass of \( \alpha \) corresponds/converts to 3.742 GeV energy
Rest mass of \( {^{14}_7N} \) corresponds/converts to 13.0942 GeV energy
Rest mass of \( {^{17}_8O} + X \) corresponds/converts to 16.8383 GeV energy

law of conservation mass – energy: \( \text{LHS}_{\text{energy}} = \text{RHS}_{\text{energy}} \)

- \( 3.7428 \text{ GeV} + 13.0942 \text{ GeV} + 7.68 \text{ MeV} = 16.8383 \text{ GeV} + \text{KE of } (^{17}_8O + X) \)
- KE of \( (^{17}_8O + X) = -0.0013 \text{ GeV} + 7.68 \text{ MeV} = -0.13 \text{ MeV} + 7.68 \text{ MeV} \)
- KE of \( (^{17}_8O + X) = 6.38 \text{ MeV} \)
(d) The reaction in (c) produces oxygen (O – 17). Other isotopes of oxygen include O – 19 which is radioactive with a half-life of 30 s.

(i) State what is meant by the term isotopes. [1]

- (nuclei of same element with) same proton number, different number of neutrons / OWTTE;

(ii) Define the term radioactive half-life. [1]

- the time for the activity of a sample to reduce by half / time for the number of the radioactive nuclei to halve from original value;
(e) A nucleus of the isotope O–19 decays to a stable nucleus of fluorine. The half-life of O–19 is 30 s. At time $t = 0$, a sample of O–19 contains a large number $N_0$ nuclei of O–19.

On the grid below, draw a graph to show the variation with time $t$ of the number $N$ of O-19 nuclei remaining in the sample. You should consider a time of $t = 0$ to $t = 120$ s.

Scale drawn on $t$ axis; (allow 10 grid squares $\equiv$ 30 s or 40 s)
smooth curve passes through $\frac{N_0}{2}$ at 30 s, $\frac{N_0}{4}$ at 60 s, $\frac{N_0}{8}$ at 90 s, $\frac{N_0}{16}$ at 120 s (to within 1 square); (points not necessary)