NAME______________________________

IB PHYSICS HL

REVIEW PACKET: NUCLEAR PHYSICS

1. This question is about nuclear reactions.

(a) Complete the table below, by placing a tick (✓) in the relevant columns, to show how an increase in each of the following properties affects the rate of decay of a sample of radioactive material.

Property	**Effect on rate of decay**		
	increase	decrease	stays the same
temperature of sample			
pressure on sample			
amount of sample			

(2)

Radium-226 ($^{226}_{88}$Ra) undergoes natural radioactive decay to disintegrate spontaneously with the emission of an alpha particle (α-particle) to form radon (Rn). The masses of the particles involved in the reaction are

radium:	226.0254 u
radon:	222.0176 u
α-particle:	4.0026 u

(b) (i) Complete the nuclear reaction equation below for this reaction.

$$^{226}_{88}\text{Ra} \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}\cdots\cdots \quad + \quad ^{\cdots\cdots}_{\cdots\cdots}\text{Rn}$$

(2)

(ii) Calculate the energy released in the reaction.

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....

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(3)

(c) The radium nucleus was stationary before the reaction.

(i) Explain, in terms of the momentum of the particles, why the radon nucleus and the α-particle move off in opposite directions after the reaction.

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.... **(3)**

(ii) The speed of the radon nucleus after the reaction is v_R and that of the α-particle is v_α. Show that the ratio $\frac{v_\alpha}{v_R}$ is equal to 55.5.

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.... **(3)**

(iii) Using the ratio given in (ii) above, deduce that the kinetic energy of the radon nucleus is much less than the kinetic energy of the α-particle.

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(3)

(d) Not all of the energy of the reaction is released as kinetic energy of the α-particle and of the radon nucleus. Suggest **one** other form in which the energy is released.

....

(1)

Another type of nuclear reaction is a fusion reaction. This reaction is the main source of the Sun's radiant energy.

(e) (i) State what is meant by a *fusion reaction*.

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(3)

(ii) Explain why the temperature and pressure of the gases in the Sun's core must both be very high for it to produce its radiant energy.

High temperature: ....

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....

....

High pressure: ....

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(5)
(Total 25 marks)

2. This question is about nuclear reactions.

(a) (i) Distinguish between *fission* and *radioactive decay*.

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(4)

A nucleus of uranium-235 ($^{235}_{92}\text{U}$) may absorb a neutron and then undergo fission to produce nuclei of strontium-90 ($^{90}_{38}\text{Sr}$) and xenon-142 ($^{142}_{54}\text{Xe}$) and some neutrons.

The strontium-90 and the xenon-142 nuclei both undergo radioactive decay with the emission of β^{-} particles.

(ii) Write down the nuclear equation for this fission reaction.

....

....

(2)

(iii) State the effect, if any, on the mass number (nucleon number) and on the atomic number (proton number) of a nucleus when the nucleus undergoes β^{-} decay.

Mass number: ....

Atomic number: ....

(2)

The uranium-235 nucleus is stationary at the time that the fission reaction occurs. In this fission reaction, 198 MeV of energy is released. Of this total energy, 102 MeV and 65 MeV are the kinetic energies of the strontium-90 and xenon-142 nuclei respectively.

(b) (i) Suggest what has happened to the remaining 31 MeV of energy.

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(2)

(ii) Calculate the magnitude of the momentum of the strontium-90 nucleus.

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(4)

(iii) Explain why the magnitude of the momentum of the strontium-90 nucleus is not exactly equal in magnitude to that of the xenon-142 nucleus.

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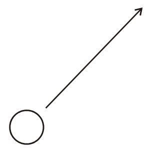
(2)

On the diagram below, the circle represents the position of a uranium-235 nucleus before fission. The momentum of the strontium-90 nucleus after fission is represented by the arrow.



(iv) On the diagram above, draw an arrow to represent the momentum of the xenon-142 nucleus after the fission. **(2)**

(c) (i) Define the *decay* constant for radioactive decay.

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.... **(2)**

(ii) The half-life of strontium-90 is 28.0 years. Deduce that the decay constant of strontium-90 is 7.85×10^{-10} s^{-1}.

....

.... **(1)**

(d) The decay constant of xenon-142 is 0.462 s^{-1}. Initially, a sample of radioactive waste material contains equal numbers of strontium-90 and xenon-142 nuclei.

(i) Use the values of the decay constants in (c) and (d) to calculate the time taken for the ratio

$$\frac{\text{number of strontium - 90 nuclei}}{\text{number of xenon - 142 nuclei}}$$

to become equal to 1.20×10^{6}.

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.... **(3)**

(ii) Suggest why, in the long-term, strontium-90 presents a greater problem then xenon-142 as radioactive waste.

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.... **(2)**

3. This question is about radioactive decay.

A nucleus of the isotope xenon, Xe-131, is produced when a nucleus of the radioactive isotope iodine I-13 decays.

(a) Explain the term *isotopes*.

....

.... **(2)**

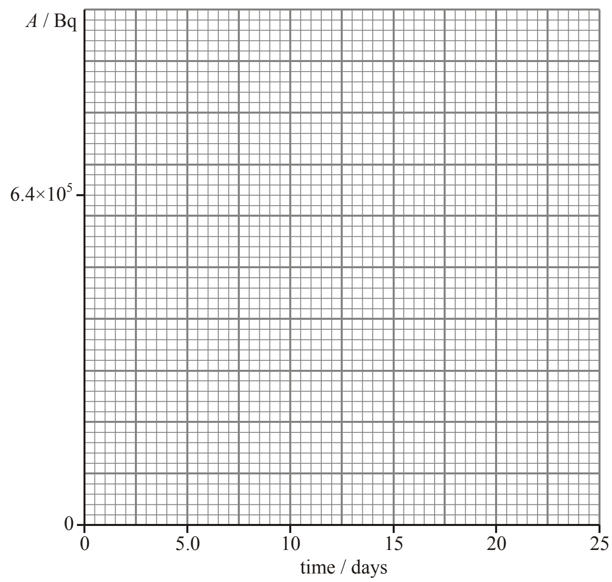
(b) Fill in the boxes below in order to complete the nuclear reaction equation for this decay.

$$^{131}_{\square}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + \beta^{-} + \square$$

(2)

The activity A of a freshly prepared sample of the iodine isotope is 6.4×10^5 Bq and its half-life is 8.0 days.

(c) Using the axes, draw a graph to illustrate the decay of this sample.



(3)

(d) Determine the decay constant of the isotope I-131

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....

(2)

The sample is to be used to treat a growth in the thyroid of a patient. The isotope should not be used until its activity is equal to 0.5×10^5 Bq.

(e) Calculate the time it takes for the activity of a freshly prepared sample to be reduced to an activity of 0.5×10^5 Bq

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(2)

4. This question is about nuclear reactions.

(a) State the meaning of the terms

(i) nuclide

....

....

....

(2)

(ii) isotope

....

....

(1)

(b) The isotope sodium-24 undergoes radioactive decay to the stable isotope magnesium-24.

(i) Complete the nuclear reaction equation for this decay.

$$ {}^{24}_{11}\mathrm{Na} \rightarrow {}^{24}_{12}\mathrm{Mg} $$

(2)

(ii) One of the particles emitted in the decay has zero rest-mass. Use the data below to estimate the rest mass, in atomic mass units, of the other particle emitted in the decay of ${}^{24}_{11}\mathrm{Na}$

rest mass of ${}^{24}_{11}\mathrm{NA}$ = 23.99096u

rest mass of ${}^{24}_{12}\mathrm{Mg}$ = 23.98504u

energy released in decay = 5.002160 MeV

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(3)

(c) The isotope sodium-24 is radioactive but the isotope sodium-23 is stable. Suggest which of these isotopes has the greater nuclear binding energy.

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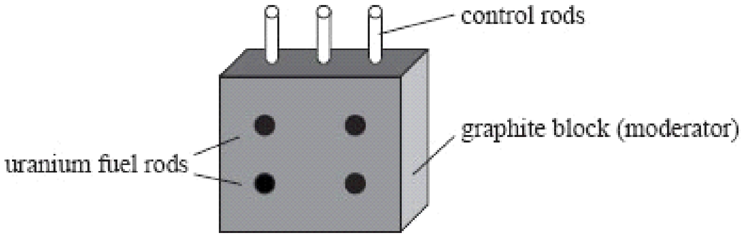
(2)

5. This question is about nuclear power production.

(a) The purpose of a nuclear power station is to produce electrical energy from nuclear energy. The diagram below is a representation of the principal components of a nuclear reactor pile used in a certain type of nuclear power station that uses uranium as a fuel.



The function of the moderator is to slow down the neutrons produced in a reaction such as that described above.

Explain,

(i) why it is necessary to slow down the neutrons.

....

....

....

....

(3)

(ii) the function of the control rods.

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....

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(2)

(b) With reference to the concept of fuel enrichment in a nuclear reactor explain,

(i) the advantage of enriching the uranium used in a nuclear reactor.

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(3)

(ii) from an international point of view, a possible risk to which fuel enrichment could lead.

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....

(2)

(c) A particular nuclear reactor uses uranium-235 as its fuel source. When a nucleus of uranium-235 absorbs a neutron, the following reaction can take place.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{144}_{54}\text{Xe} + ^{90}_{38}\text{Sr} + 2^{1}_{0}\text{n}$$

The following data are available.

rest mass of $^{235}_{92}\text{U}$ = 2.1895×10^5 MeV c^{-2}

rest mass of $^{144}_{54}\text{Xe}$ = 1.3408×10^5 MeV c^{-2}

rest mass of $^{90}_{38}\text{Sr}$ = 8.3749×10^4 MeV c^{-2}

rest mass of $^{1}_{0}\text{n}$ = 939.56 MeV c^{-2}

(i) Show that the energy released in the reaction is approximately 180 MeV.

....

....

(1)

(ii) State the form in which the energy appears.

....

(1)

(d) The energy released by 1 atom of carbon-12 during combustion is approximately 4 eV.

(i) Using the answer to (c)(i), estimate the ratio

$$\frac{\text{energy density of uranium - 235}}{\text{energy density of carbon - 12}}.$$

....

....

....

(3)

(ii) Suggest, with reference to your answer in (d)(i), **one** advantage of uranium-235 compared with fossil fuels.

....

.... **(1)**

(e) When a uranium-238 nucleus absorbs a neutron the following reaction can take place.

$$^{238}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{239}_{92}\text{U}$$

The isotope uranium-239 is radioactive and decays with a half-life of 23 minutes to form an isotope of neptunium-239 (Np-239).

(i) Define *radioactive half-life* and explain what is meant by an isotope.

Radioactive half-life:

....

Isotope:

....

(2)

(ii) Complete the reaction equation for this decay.

$${}^{239}_{92}\text{U} \rightarrow$$ **(3)**

(iii) The isotope neptunium-239 undergoes radioactive β^{-} decay to form an isotope of plutonium. Outline **one** advantage and **one** disadvantage of this decay in relation to nuclear power production.

Advantage:

....

....

Disadvantage:

....

.... **(4)**

6. This question is about the production of nuclear energy and its transfer to electrical energy.

(a) When a neutron "collides" with a nucleus of uranium-235 (${}^{235}_{92}$U) the following reaction can occur.

$${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{144}_{56}\text{Ba} + {}^{90}_{36}\text{Kr} + 2\,{}^{1}_{0}\text{n}$$

(i) State the name given to this type of nuclear reaction.

.... **(1)**

(ii) Energy is liberated in this reaction. In what form does this energy appear?

.... **(1)**

(b) Describe how the neutrons produced in this reaction may initiate a chain reaction.

.... **(2)**

7. This question is about radioactivity.

(a) A sample of radioactive material is found by chemical analysis to contain 8.90×10^{19} atoms of uranium-235. The activity of the sample is 4.25×10^{2} Bq.

Calculate, for the uranium-235

(i) the decay constant;

....

.... (2)

(ii) the half-life in years.

....

.... (2)

(b) An isotope has a half-life of approximately four hours. Suggest why measurement of the number of atoms and the activity of a sample of this isotope cannot be used to determine its half-life.

....

.... (1)

MARK SCHEME!

1. (a) *Deduct **[1]** for each error or omission, stop at zero* 2 max

Property	***Effect on rate of decay***		
	increase	*decrease*	*stays the same*
temperature of sample			✓
pressure on sample			✓
amount of sample	✓		

(b) (i) ${}^{4}_{2}\text{He} / {}^{4}_{2}\alpha$;

${}^{222}_{86}\text{Rn}$; 2

(ii) mass defect = 5.2×10^{-3} u;

energy = mc^2

= $5.2 \times 10^{-3} \times 1.661 \times 10^{-27} \times 9.00 \times 10^{16}$ / 1 u = 930 MeV;

= 7.77×10^{-13} J / 4.86 MeV; 3 max

(c) (i) (linear) momentum must be conserved;
momentum before reaction is zero;
so equal and opposite after (to maintain zero total); 3

(ii) $0 = m_\alpha v_\alpha + m_{\text{Rn}} v_{\text{Rn}}$;

$$\frac{v_\alpha}{v_{\text{Rn}}} = -\left(\frac{m_{\text{Rn}}}{m_\alpha}\right)$$

$= -\frac{222}{4} = -55.5$; 3

Ignore absence of minus sign.

(iii) kinetic energy of α-particle = $\frac{1}{2} m_\alpha v_\alpha^2$;

kinetic energy of radon nucleus = $\frac{1}{2}\left(\frac{222}{4}\right) m_\alpha \left(\frac{V_\alpha}{55.5}\right)^2$;

this is 1 / 55.5 of kinetic energy of the α-particle; 3 max

*Accept alternative approaches up to **[3 max]**.*

(d) *eg* (γ-ray) photon energy or radiation; 1

(e) (i) two (light) nuclei;
combine to form a more massive nucleus;
with the release of energy / with greater total binding energy; 3

(ii) high temperature means high kinetic energy for nuclei;
so can overcome (electrostatic) repulsion (between nuclei);
to come close together / collide;
high pressure so that there are many nuclei (per unit volume);
so that chance of two nuclei coming close together is greater; 5

2. (a) (i) *fission*:
nucleus splits;
into two parts of similar mass;

radioactive decay:
nucleus emits;
a particle of small mass and / or a photon; 4

(ii) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n}$;
$\rightarrow {}^{90}_{38}\text{Sr} + {}^{142}_{54}\text{Xe} + 4{}^{1}_{0}\text{n}$; 2

Allow ecf for RHS if LHS is incorrect.

(iii) mass number unchanged;
atomic number increases by +1; 2

(b) (i) kinetic energy of neutrons;
and energy of gamma ray photons; 2

Accept other valid possibilities but do not accept "heat".

(ii) use of $E_k = \frac{p^2}{m}$ / equivalent;
correct conversion of MeV to joule (1.63×10^{-11} J);
correct conversion of mass to kilogram (1.50×10^{-25} kg)
momentum = 2.2×10^{-18} N s; 4

(iii) total momentum after fission must be zero;
must consider momentum of neutrons (and photons); 2

(iv) xenon not opposite to strontium but deviation < 30°);
arrow shorter / longer; 2

(c) (i) probability of decay / constant in expression $\frac{dN}{dt} = -\lambda N$;
per unit time / $\frac{dN}{dt}$ and N explained; 2

(ii) $\lambda = \frac{\ln 2}{(28 \times 365 \times 24 \times 3600)}$ (***note**: substitution is essential)*
$= 7.85 \times 10^{-10}\ \text{s}^{-1}$; 1

(d) (i) $\frac{N_0 \exp(-7.85 \times 10^{-10}\, t)}{N_0 \exp(-0.462t)} = 1.2 \times 10^6$;
$\exp(0.462t) = 1.2 \times 10^6$;
$t = 30.3$ s; 3

(ii) activity of the strontium will be much greater than that of the xenon;
and extent of health hazard depends on activity; 2

[26]

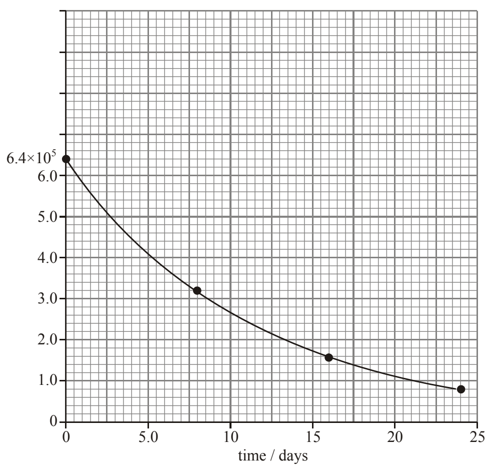
3. (a) the nuclei of different isotopes of an element have the same number of protons;
but different numbers of neutrons; 2

Look for a little more detail than say just "same atomic (proton) number, different mass (nucleon) number".

(b) Z for iodine = 53;
+ antineutrino; *(accept symbol)* 2

Do not accept neutrino or gamma or energy, etc.

(c)



shown on graph at least the 0, 8 and 16 day data points;
exponential shape;
scale on *y*-axis / goes through 24 day point; 3

(d) $\lambda = \dfrac{0.69}{T}$; (*accept ln 2 for 0.69*)
$= 0.086\ \text{d}^{-1}$ / $0.87\ \text{d}^{-1}$ / $1.0 \times 10^{-6}\ \text{s}^{-1}$; 2

(e) $0.5 = 6.4e^{-0.086t}$;
to give t = 30d / 2.6×10^{6} s / 29d / 2.5×10^{6} s; 2

[11]

4. (a) (i) an atom or nucleus that is characterized by the constituents of its nucleus / a particular type of atom or nucleus / *OWTTE*;
(in particular) by its proton (atomic) number and its nucleon number / number of protons and number of neutrons; 2

(ii) nuclides that have the same proton number but different nucleon number / same number of protons different number of neutrons; 1

(b) (i) $^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + \beta^{-} + \bar{\nu}$
β^{-} / e^{-} / $^{0}_{-1}e$;
$\bar{\nu}$; 2

(ii) 5.00216 MeV is equivalent to 0.00537 *u*;
23.99096 = 23.98504 + 0.00537 + rest mass of particle;
rest mass= 0.00055 *u*; 3
No credit given for bald correct answer.

(c) sodium-24 has more nucleons;
and more nucleons (usually) means greater (magnitude of) binding energy;

or

sodium-23 has less nucleons;
and less nucleons (usually) means less (magnitude of) binding energy; 2

5. (a) (i) there is more uranium-238 present than uranium-235;
neutron capture is more likely in U-238 with high energy neutrons;
if the neutrons are slowed they are more likely to produce fission in U-235 than neutron capture in U-238; 3

(ii) control rate at which reactions take place;
by absorbing neutrons; 2

(b) (i) fuel enrichment means that the amount of uranium-235 present in the fuel is increased / *OWTTE*;
this means that more U-235 available for fission;
therefore the reaction can be sustained; 3

(ii) enriched fuel can be used in the manufacture of nuclear weapons;
so possibly threatening World peace; 2

(c) (i) (energy released) = $2.1895 \times 10^5 - (1.3408 + 0.83749 + 0.0093956) \times 10^5$;
$= 181.44 \approx 180$MeV 1

(ii) kinetic; 1

(d) (i) number of atoms in 1 kg of carbon = $\frac{12\times1000}{N_A}$ and number in 1 kg of U-235 = $\frac{235\times1000}{N_A}$;

energy per kg carbon = $\frac{12\times4}{N_A}$ keV and per kg U-235 = $\frac{235\times1.8\times10^8}{N_A}$ keV;

therefore ratio = 8.8×10^8; 3

(ii) a much higher energy density implies that uranium will produce more energy per kg / smaller quantity of uranium needed to produce same amount of energy / *OWTTE*; 1

(e) (i) *half-life:*
time for the activity to decrease by half / *OWTTE*;

isotope:
isotopes of elements are chemically identical but have different atomic masses / *OWTTE* / same number of protons in the nucleus but different number of neutrons / *OWTTE*; 2

(ii) $^{239}_{92}\text{U} \rightarrow {}^{239}_{93}\text{Np} + \beta^- + \bar{\nu}$

$^{239}_{93}\text{Np}$;

β^-;

$\bar{\nu}$; 3

(iii) *advantage:*
plutonium is another fissionable element / may be used as nuclear fuel;
and is readily produced in reactors that use uranium as a fuel;

disadvantage:
β-particles are harmful to living organisms / *OWTTE*;
and the plutonium lasts for a very long-time / *OWTTE*; 4

[25]

6. (a) (i) fission 1 max

(ii) kinetic energy 1 max

(b) the two neutrons can cause fission in two more uranium nuclei producing four neutrons so producing eight *etc*; *OWTTE*; 1 max

7. (a) (i) activity = (–)λN;

$$\lambda = \frac{4.25\times10^{2}}{8.90\times10^{19}} = 4.78\times10^{-18}\ \text{s}^{-1};$$ 2

Allow $1.51\times10^{-10}\ yr^{-1}$.

(ii) $$T_{1/2} = \frac{\ln 2}{4.78\times10^{-18}} = 1.45\times10^{17}\ \text{s};$$

$= 4.60\times10^{9}$ years; 2

(b) *eg* activity would change during analysis to find *N* / rate of change of activity is too great to allow N(t) to be determined / *OWTTE*; 1

[5]