Questions on Nuclear Physics

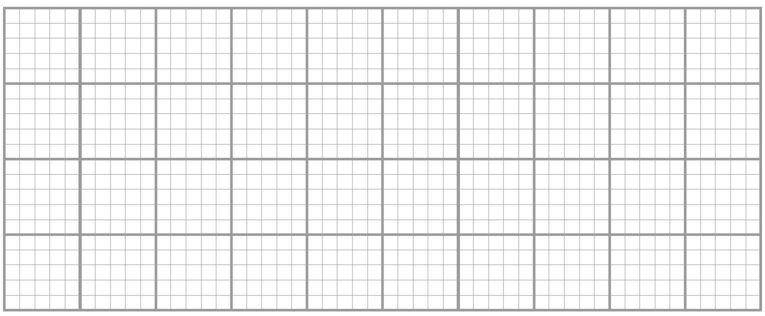
1. The Radiocat website says:

R A D I O C A T

A one shot deal!

Older cats often get benign tumours of the thyroid gland, but Radiocat can deal with these. One injection of radioiodine $^{131}_{53}\mathrm{I}$ is all it takes! The $^{131}_{53}\mathrm{I}$ is absorbed into the thyroid and destroys the thyroid tumour. Our treatment plan includes $^{131}_{53}\mathrm{I}$ injection and daily monitoring with as much love and care as we can safely give. Your cat must reach a safe and legal level of radioactivity before coming home.

The $^{131}_{53}\mathrm{I}$ has a half-life of 8 days and, when first injected, its activity is 80 MBq. On the axes below, sketch a graph showing how the activity changes with time for 24 days after the injection.



(2)

$^{131}_{53}\mathrm{I}$ emits β-particles and γ-rays.

Describe the composition of the nucleus of $^{131}_{53}\mathrm{I}$.

....

....

State two differences between a β-particle and a γ-ray.

....

....

(4)

During its stay in the clinic the cat cannot be given much "love and care". Explain this statement.

....

....

....

A safe level of radiation release is 50 MBq. Calculate how long a cat must stay at the clinic before it is allowed home.

....

....

....

....

....

Length of time =...

(4)

State one assumption you made in the calculation above.

....

....

(1)
(Total 12 marks)

2. The equations below represent a typical fission and a typical fusion reaction.

$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{138}_{55}\text{Cs} + {}^{96}_{37}\text{Rb} + \text{X}\,{}^{1}_{0}\text{n}$ $^{3}_{2}\text{He} + {}^{3}_{2}\text{He} \rightarrow {}^{4}_{2}\text{He} + \text{Z}\,\text{p}$

State the values of X and Z for the two nuclear equations above.

....

....

....

....

X = ...   Z = ...

(2)

Write a short account of the physics of nuclear fission and fusion explaining the similarities and differences between them. You may include diagrams in the space below.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(5)
(Total 7 marks)

3. Scientists have worked out the age of the Moon by dating the rocks brought back by the Apollo missions. They use the decay of potassium-40 to stable argon-40 in the rocks; this process has a half life of 1.3×10^9 years. In one rock sample, the scientists found 0.84 μg of argon-40 and 0.10 μg of potassium-40.

Use the data above to calculate the age of the Moon.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

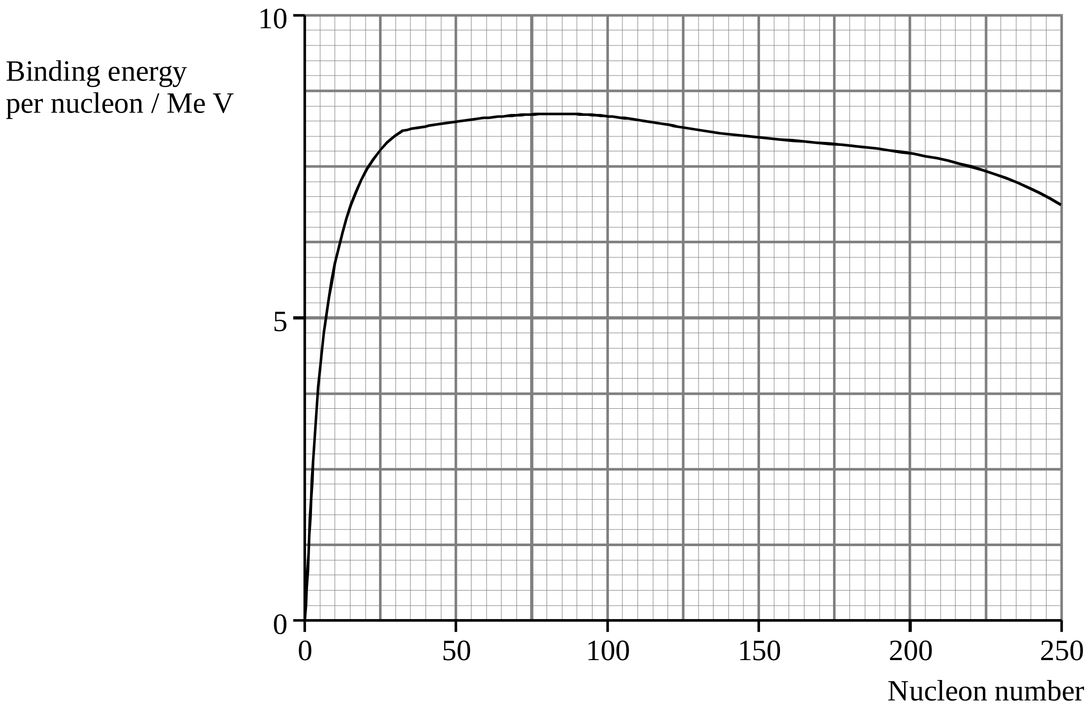
....

....

....

(Total 6 marks)

4. Nuclear power stations use the fission of uranium-235 to produce thermal energy. The simplified graph below can be used to explain energy transformation by nuclear fission



What is meant by binding energy?

....

....

....

(1)

Use the graph to estimate the binding energy (in eV) of a nucleus of uranium-235.

....

....

....

Binding energy = ... eV

(2)

When a uranium-235 nucleus undergoes fission, two smaller nuclei are formed, each with about half the number of nucleons.

Show that the energy released in the fission of one nucleus of uranium-235 is about 4×10^{-11} J.

....

....

....

....

....

....

(3)

1.0 kg of uranium-235 contains 2.6×10^{24} nuclei.

Calculate the energy released by the fission of 1.0 kg of uranium-235.

....

....

Energy = ...

(1)
(Total 7 marks)

5. What do we call the nuclear radiation which is around us all the time?

....

(1)

Name one source of this radiation.

....

(1)

Suggest why our exposure to radiation is greater today than it was 100 years ago.

....

(1)

In factories that produce fabric from synthetic fibres, there may be problems due to the build-up of static charge on the fabric. Beta radiation can be used to reduce the problem.

(i) Give two reasons why beta radiation is chosen rather than gamma radiation.

....

....

....

(ii) Why is beta radiation chosen rather than alpha radiation?

....

....

(3)

Gamma radiation is used for detecting flaws in an aircraft wing. Why is gamma radiation suitable in this application?

....

....

....

....

....

(2)
(Total 8 marks)

6. The Huygens/Cassini space mission to Titan, a moon of Saturn, left the Earth amid a storm of protest. The protest was about its nuclear-powered battery which contained plutonium-238, an alpha emitter. Before launch in 1997, a newspaper article read

> **PLUTONIUM PROBE PERIL**
>
> NASA is going to send up a space probe with 70 pounds of deadly plutonium on board. The probe is going to be launched using a Titan IV rocket – the same type of rocket that blew up over the Pacific Ocean just 4 years ago in 1993.
>
> Plutonium is so deadly that just one pound of it, spread through the Earth's atmosphere, could cause lung cancer in every person on Earth! Less than one millionth of a gram of it is a deadly dose.

In plutonium-238, what does 238 mean?

....

....

(1)

Why did the plutonium source cause concern?

....

....

(1)

The half-life of plutonium-238 is 88 years and, at launch, the source contained 7.2×10^{25} atoms. Show that the activity of the plutonium source, at the time of launch, was about 2×10^{16} Bq.

(1 year = 3.16×10^7 s)

....

....

....

....

....

(3)

Each plutonium nucleus releases 5.6 MeV when it decays. Calculate the power (in watts) delivered by the plutonium at the time of the rocket launch.

....

....

....

Power = ...

(3)

The textbooks say that nuclear decay is a random process. Explain whether this means that there is some doubt that the power can be relied upon.

....

....

....

(1)

What percentage of the power at launch will still be available 10 years after the launch?

....

....

....

....

....

....

Percentage = ...

(2)

Suggest why plutonium was chosen for this mission.

....

....

(1)
(Total 12 marks)

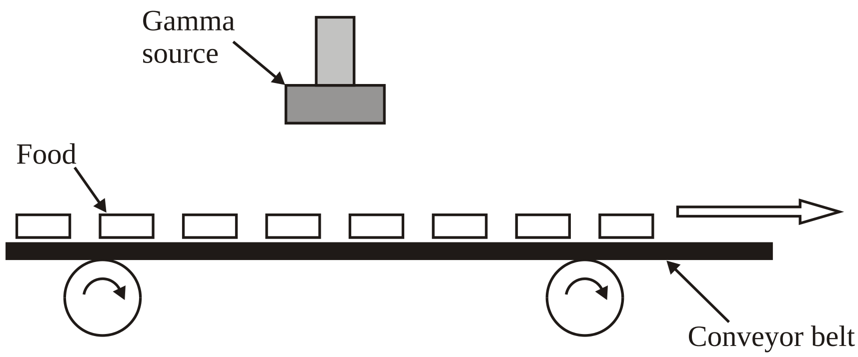
7. Radioactive isotopes emitting gamma radiation can be used to preserve food. The food is exposed to the radiation which kills most of the bacteria that occur naturally.

Why is gamma radiation used in this process rather than alpha or beta?

....

(1)

The food is passed on a conveyor belt under a radiation source.



State **two** factors which control the amount of radiation reaching each item of food.

....

....

(2)

A thick wall surrounds the irradiation room to prevent the radiation escaping. Suggest a suitable material and thickness for this wall.

....

....

(2)

Many consumers are worried about irradiated food, as they wrongly believe that this makes it become radioactive. Food does, however, contain a small level of naturally occurring radiation. Name something other than food that is also a source of natural radiation.

....

(1)
(Total 6 marks)

8. **Carbon clock could show the wrong time**

This was the headline of a news report in Physics Web in May 2001 about some stalagmites found in a cave in the Bahamas.

Stalagmites are found in limestone caves and are long, thin rocks formed by the deposition of calcium carbonate from solution. The stalagmites in the news report are a half-metre long. They contain atoms of the radioactive isotope carbon-14, which has a half-life of 5730 years. The decay of carbon-14 can be used to determine the age of objects. This process is called radiocarbon dating.

In one part of the stalagmites, $\frac{255}{256}$ of the carbon-14 atoms have decayed.

Determine the age of this part of the stalagmite.

....

....

....

....

....

Age = ...

(3)

Some parts were formed much more recently. How would this affect their carbon-14 concentration?

....

(1)

However, scientists have found that the level of carbon-14 when the oldest parts of the stalagmites were formed was twice the modern level. Discuss the effect on the validity of radio-carbon dating.

....

....

....

....

....

(3)
(Total 7 marks)

9. In April 1986 an explosion destroyed one of the reactors at Chernobyl Nuclear Power Station. In the accident, radioisotopes were scattered over the surrounding area and many were carried large distances by the wind. The contamination included isotopes of strontium, iodine, caesium and plutonium.

Data on these isotopes are shown below:

Isotope	Proton number	Half-life	Particles emitted
^{90}Sr	38	28 years	β
^{131}I	53	8.1 days	β, γ
^{134}Cs	55	2.1 years	β, γ
^{137}Cs		30 years	β, γ
^{239}Pu	94	24 000 years	α, γ
^{240}Pu		6600 years	α, γ

Fill in the missing proton numbers.

(1)

The fuel for the power station originally consisted of uranium ($^{235}_{92}U$ and $^{238}_{92}U$).

(i) Name the process which produced strontium and caesium.

....

(ii) Suggest how plutonium was formed in the nuclear reactor.

....

....

....

(2)

In **June** 1986, the area around the power station was still dangerously contaminated, with so much ^{137}Cs in the ground that it emitted 1.5×10^6 Bq m^{-2}. Calculate the emission rate which would be recorded today from this same ground, stating any assumptions which you make.

....

....

....

....

....

....

Emission rate = ...Bq m^{-2}

Assumption: ……………………………………………………………………………..

....

(4)

Explain which of the scattered isotopes would no longer be of concern today.

....

....

....

....

(2)

Some politicians say that the Chernobyl accident happened so long ago that it is no longer dangerous to live in the area. Comment on this statement.

....

....

....

....

(2)
(Total 11 marks)

10. Nuclear power stations use nuclear fission to provide energy for electricity generation. When a nucleus of ^{235}U absorbs a neutron, it becomes unstable and undergoes fission, producing two lighter nuclei and some more neutrons. A typical reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + \text{neutrons}$$

The neutrons released can produce more fission reactions if they are captured by further ^{235}U nuclei. A reactor in a power station contains neutron-absorbing materials designed so that the chain reaction proceeds at a steady rate.

The energy released per unit mass of nuclei fuel is several orders of magnitude greater than that produced by burning chemical fuels such as oil or gas. After use, the spent fuel can be chemically treated to extract any useful materials. The remaining waste is highly radioactive.

How many neutrons are produced in the reaction above? Explain your reasoning.

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

(2)

Explain why a nuclear fission reaction releases energy.

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

(2)

An isotope $^{238}_{92}U$ is also present within the fuel rods of a nuclear reactor. It absorbs neutrons and heavier nuclei are produced. $^{239}_{94}Pu$ (plutonium) is one of these products and is particularly hazardous. $^{239}_{94}Pu$ has a half-life of 24 400 years and decays by alpha emission.

A quantity of plutonium is extracted from the fuel rods. Calculate the fraction of these $^{239}_{94}Pu$ nuclei which remain after one thousand years.

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

Fraction = ……………………………..

(3)

Calculate the percentage decrease in the activity due to ${}^{239}_{94}\text{Pu}$ over this period of time.

…....…....…...…...…...…...…...…...…...…...…...…...…...…...…...…...…...…....….…………

Decrease in activity = ..…...…...…...…...….………..

(1)

In fact, if you started with a sample of pure ${}^{239}_{94}\text{Pu}$ the activity of the sample after one thousand years would be greater than indicated by your answer above. Suggest a reason for this.

…....…....…...…...…...…...…...…...…...…...…...…...…...…...…...…...…...…....….…………

…....…....…...…...…...…...…...…...…...…...…...…...…...…...…...…...…...…....….…………

(1)
(Total 9 marks)

11. Fission of ${}^{235}\text{U}$ (uranium-235) nuclei is used to provide the energy to heat the core of a nuclear reactor.

A typical fission reaction is given in the equation

$$ {}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{111}_{44}\text{Ru} + {}^{122}_{48}\text{Cd} + 3\,{}^{1}_{0}\text{n} + \text{energy} $$

Write down the number of protons and neutrons in the isotope of cadmium produced, ${}^{122}\text{Cd}$.

Protons .... Neutrons ....

(2)

Describe briefly the process which occurs in a fission reaction.

....

....

....

....

....

(3)

The fission of one ${}^{235}\text{U}$ nucleus in the equation above releases 3.2×10^{-11} J of energy.
Calculate the change in mass which occurs in this reaction.

....

....

....

(2)

A nuclear power station, which uses the fission of ^{235}U nuclei, generates 660 MW of electrical power and is 30% efficient. Calculate the number of fissions required each second to produce this power.

....

....

....

....

....

Number of fissions per second = ...

(2)

This number of atoms has a mass of less than a gram. Give **two** reasons why it is necessary to have a lot more fuel than this in a nuclear reactor.

....

....

....

....

....

(2)
(Total 11 marks)

12. Young people have swum for many years in an unusually warm Siberian river near to a secret nuclear fuel reprocessing factory. This factory has made regular discharges of nuclear waste into the river.

Why is the river **unusually warm?**

....

....

(1)

Alpha (α), beta (β) and gamma (γ) radiation can be emitted by the radioactive waste. What are each of these?

α ....

....

β ....

....

γ ....

....

(3)

For the swimmers' health, which are the most hazardous radioactive nuclei in the water: those emitting α, β or γ radiation?

....

Explain your answer.

....

....

....

....

(2)

Some people say that the water would still be radioactive if the factory were not there, since we live in a radioactive world. Where could this radioactivity come from?

....

....

(1)
(Total 7 marks)