Australian Government

Nuclear-based science benefiting all Australians

Year 11 and 12

Chemistry Workbook

The aim of this workbook is to provide you with information and questions to assist you in your study areas of Nuclear Chemistry and Chemical Monitoring and Management as outlined below.

This workbook is a guide only – your teacher is the final authority

9.2 Production of Materials

5. Nuclear chemistry provides a range of materials

Students learn to:

- distinguish between stable and radioactive isotopes and describe the conditions under which a nucleus is unstable
- describe how transuranic elements are produced
- describe how commercial radioisotopes are produced
- identify instruments and processes that can be used to detect radiation
- identify one use of a named radioisotope:
  - in industry
  - in medicine
- describe the way in which the above named radioisotopes are used and explain their use in terms of their chemical properties

Students:

- process information from secondary sources to describe recent discoveries of elements
- use available evidence to analyse benefits and problems associated with the use of radioactive isotopes in identified industries and medicine

9.4 Chemical Monitoring and Management

1. Much of the work of chemists involves monitoring the reactants and products of reactions and managing reaction conditions

Students learn to:

- outline the role of a chemist employed in a named industry or enterprise, identifying the branch of chemistry undertaken by the chemist and explaining a chemical principle that the chemist uses
- identify the need for collaboration between chemists as they collect and analyse data
- describe an example of a chemical reaction such as combustion, where reactants form different products under different conditions and thus would need monitoring

Students:

- gather, process and present information from secondary sources about the work of practising scientists identifying:
  - the variety of chemical occupations
  - a specific chemical occupation for a more detailed study

Your visit to ANSTO

The tour will commence at the Discovery Centre where one of our Education Officers will provide an introduction and overview. This will include demonstrations of various aspects of nuclear chemistry using low level radioactive sources.

You will then visit:

- OPAL (Open Pool Australian Lightwater) Reactor
  - you will see models of the reactor and look deep into the reactor pool through live CCTV
- Neutron Guide Hall
  - from a viewing platform you will see the facilities and instruments used in materials and biological research using neutrons produced in OPAL
- Centre for Accelerator Science, part of our Institute for Environmental Research
  - here you will see one or more particle accelerators used to conduct many different types of analyses including radiocarbon dating
- Other facilities if time permits

The tour will conclude at the Discovery Centre. We have a number of brochures that you may wish to collect or they can be accessed on our website.

PART A

Pre Tour Questions

This section is designed to be completed by students prior to visiting ANSTO. It consists of questions on concepts from junior years that are essential to an understanding of the nuclear science to be covered in the tour.

Question 1
Atoms are made up of 3 sub-atomic particles: protons, neutrons and electrons. Choose options from the following lists to complete the table:

in nucleus	negligible	0
surrounding the nucleus	1	+1
in nucleus	1	-1

Particle	Location	Mass in atomic mass units (amu)	Charge
Proton			
Neutron			
Electron			

Nuclear Facts To Remember:

1. The number of protons in an atom is the **atomic number (Z)**.
2. The number of protons plus neutrons is the **mass number (A)**.
3. In a neutral atom, the number of protons and number of electrons are equal.

The atomic number, Z, determines what element the atom is, for example:
Z = 1, atom is hydrogen, symbol H
Z = 6, atom is carbon, symbol C

The notation for representing an atom is as follows:

$${}^{A}_{Z}X$$

X = symbol of element
A = number of (protons + neutrons)
Z = number of protons

As the symbol or the Z-number uniquely identifies the element, only one of these **must** be present.

When naming atoms, we use the name or symbol of the element, followed by the mass number. For example: hydrogen-1 (or H-1) and carbon-12 (or C-12). The notation for these is:

${}^{1}_{1}H$ or ${}^{1}H$ and ${}^{12}_{6}C$ or ${}^{12}C$

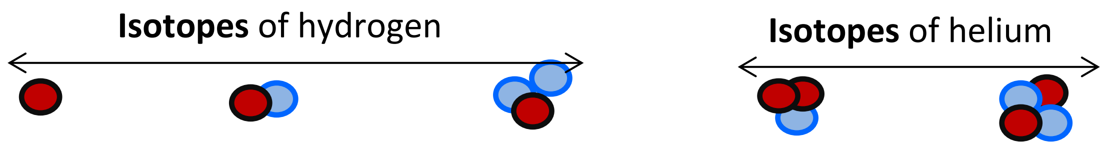
Question 2
Refer to a periodic table to complete the following table:

Name of atom	Number of protons	Number of neutrons	Mass number	Notation
nitrogen-14				
	3		7	
				${}^{1}_{9}F$
		14	27	

Isotopes of Elements

The nuclei for the five smallest atoms and their names are shown in the diagram below. Nearly all atoms contain protons and neutrons. The hydrogen atom, hydrogen-1, is the only atom that does not contain neutrons.

Key: proton neutron



hydrogen-1 hydrogen-2 (deuterium) hydrogen-3 (tritium) helium-3 helium-4

Question 3

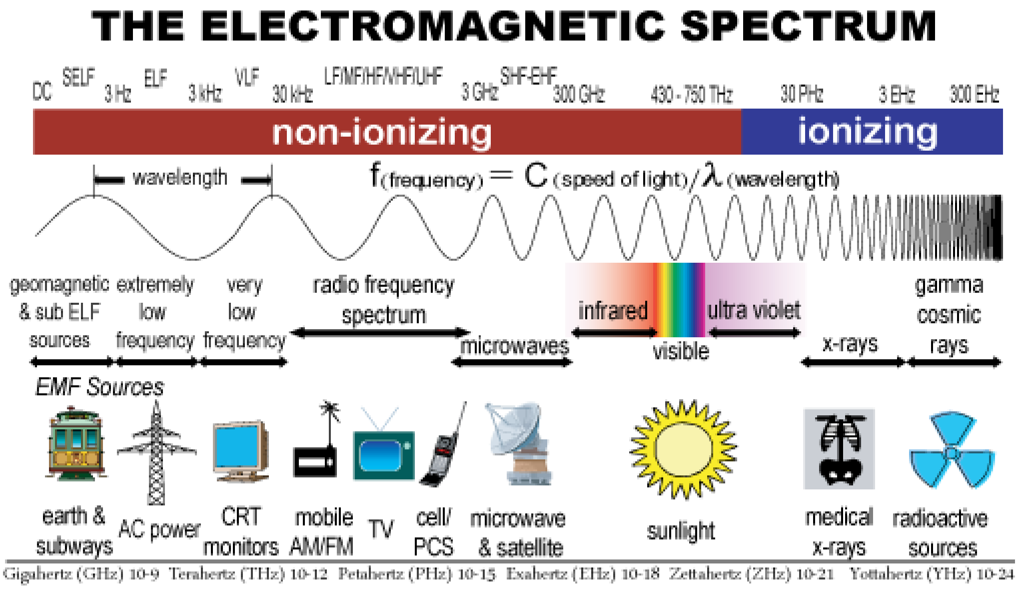
Using the information above, define the term ‘isotope’

____

____

Electromagnetic spectrum

The electromagnetic spectrum below shows that radiation occurs in waves. It can be explained as packets of light, or photons, of different energy. The type of radiation depends on the amount of energy it has. Gamma rays are at the high energy end of the spectrum whilst radio waves are at the low energy end.



Question 4

Delete the incorrect terms in the following sentence.

The shorter the wavelength, the **greater/lower** the energy. Therefore ultraviolet radiation has **more/less** energy than infrared radiation but **more/less** than gamma rays.

Nuclear Radiation – Radioactivity

In 1896 French scientist Henri Becquerel discovered a new kind of invisible radiation that seemed to be emitted from a uranium-rich rock. This radiation could not be stopped, increased or decreased. This was nuclear radiation and it was something completely new to science.

Marie Curie, working in Paris, coined the term 'radioactivity' to describe this new property, and discovered three new radioactive elements.

It is the structure of the nucleus of an atom that determines whether it is **radioactive**, or in other words, unstable. Unstable atoms undergo **radioactive decay.**

Further studies by New Zealander Ernest Rutherford showed that there are three different types of radioactivity. He named them after the first 3 letters of the Greek alphabet: alpha (α), beta (β) and gamma (γ) radiation. Each of these types has its own characteristic properties. You should recall these properties from your junior years.

Question 5

Complete the following table for the three types of radioactive decay.

Name	Symbol	Consists of	Charge	Mass
Alpha	α	Helium-4 nucleus		
Beta	β			Negligible
Gamma	γ		0	

Radioactive atoms, called **radioisotopes**, may emit only one type of radiation but it is more common for an alpha or beta decay to be accompanied by a gamma emission.

PART B

This section is designed to be completed by students whilst visiting ANSTO. It consists of questions covering concepts that will be explained during the tour.

Lecture Questions

Question 1

What is ‘nuclear science’?

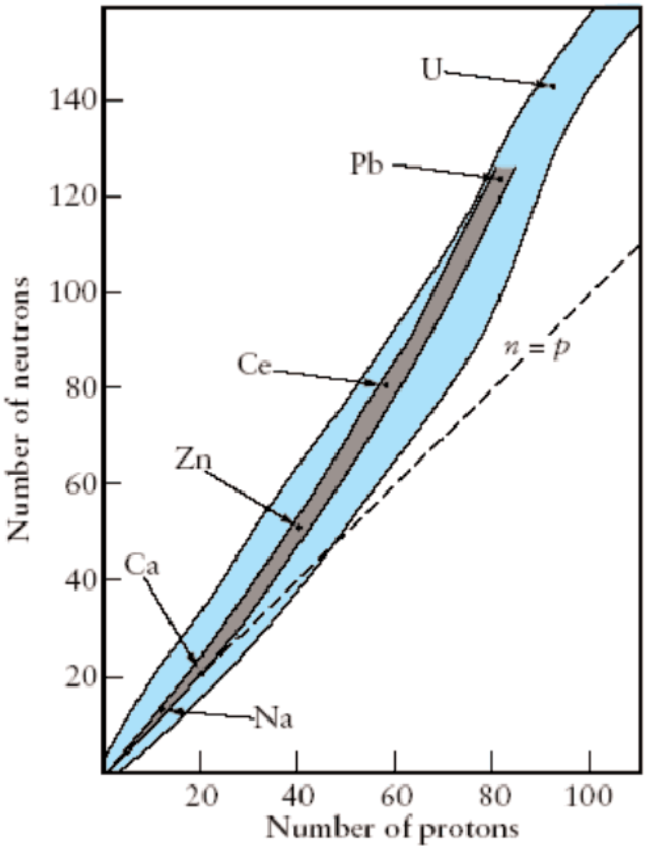
____

Question 2

ANSTO uses nuclear science in many different research and commercial areas. Name some of these areas.

____

____



All the stable nuclei lie within a definite area called the **zone of stability** – the central grey area in the graph.

For low atomic numbers most stable nuclei have a neutron/proton ratio which is very close to 1.

As the atomic number increases, the zone of stability corresponds to a gradually increasing neutron/proton ratio.

Question 3

Using the above information and from the lecture, give 4 reasons why isotopes may be unstable.

1) ____

2) ____

3) ____

4) ____

Question 4

a) ANSTO runs a facility, the Gamma Technology Research Irradiator, called _____________. The facility utilises the radioisotope ___________ to irradiate a number of different targets with gamma radiation. Name three of the targets:

i) ____________________

ii) ____________________

iii) ____________________

b) For one of these, briefly outline the reasons why the irradiation is done.

____

____

Question 5

Radioactivity may be detected in a number of ways. These include:

a) Photographic film/paper

b) Cloud chamber

c) ___________________________

d) ___________________________

Today the Education Officer will be using a _____________________ counter to measure the activity of a number of low-level sources. Complete the following table as they are measured. (See the Appendix for a brief explanation of the units of radiation.)

Item	Radioisotope(s) present	Measurement (cps or Bq)
Background radiation		
Potash fertiliser (potassium sulphate)		
Tungsten welding rods		
Citrene glass		
Gas mantles		
Watch		
Autenite mineral		
Fiestaware		

Question 6: Factors Affecting Amount of Exposure to Radiation

Three things that affect the amount of exposure are:

1. The greater the _____________ exposed, the greater the exposure.

2. The greater the ______________ from the _____________ , the lower the exposure.

3. Exposure can be reduced by ______________ . Three good materials for this are:

__________________ , __________________and __________________

Question 7: Medical Radioisotopes

Fill in the blanks in the following:

a) __________________ is used for Positron Emission Tomography, or PET scans and is produced in a __________________.

b) Molybdenum-99 (Mo-99) is formed in a fission reaction within a target containing uranium in the OPAL reactor.

Mo-99, with a half-life of _____ hours, undergoes negative beta and gamma decay to form __________________, which has a half-life of 6 hours.

On Site Questions

Monitoring Radiation Exposure

Workers in environments where exposure to radiation is possible wear devices that monitor and measure the amount of exposure. Two such devices are shown below and will be worn by your Education Officer today while on site.

Electronic Personal Dosimeter

Thermo Luminescent Dosimeter

Question 1

An EPD measures ____

A TLD measures ____

A. OPAL Reactor

OPAL Reactor building

OPAL Reactor pool complex

Question 2

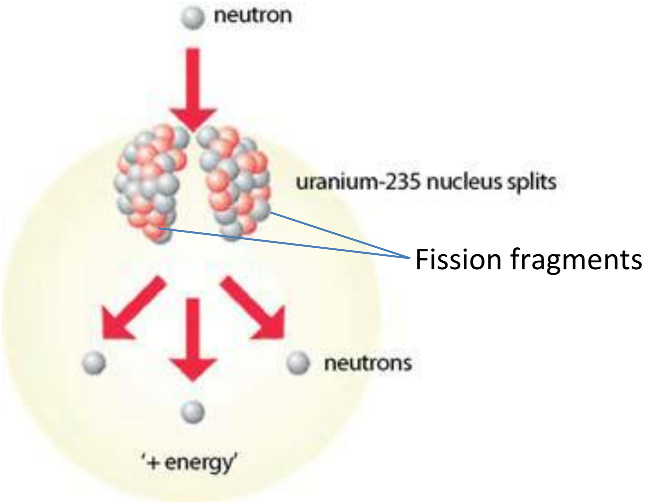
Nuclear fission of U-235 in the core of the OPAL reactor produces neutrons. Essentially the reactor is a neutron factory with the neutrons being used for a variety of purposes. Name 3:

1. ____

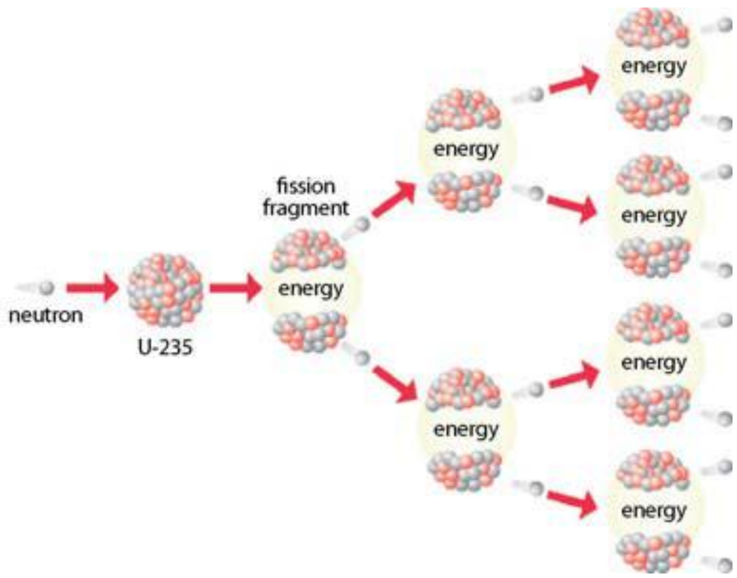
2. ____

3. ____

Nuclear fission starts when a U-235 atom is impacted by a neutron and the U-235 atom splits into 2 fragments called fission fragments. A number of neutrons are also produced. The diagram below shows nuclear fission.



If the nuclear fission is not **controlled**, a chain reaction can occur, as shown:



Question 3

How is the nuclear fission in the core of OPAL controlled?

____

____

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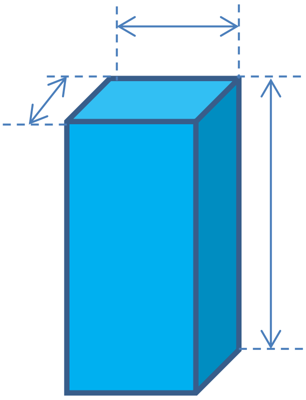
Question 4

a) Complete the approximate dimensions of the core



b) How many fuel assemblies make up the core? ______________

c) What is the total mass of uranium in the OPAL core? ______________

d) What is the enrichment level of uranium-235 in the core? ______________

Question 5

a) What two materials are used as moderators in the OPAL reactor? For each state what it is that they moderate.

i) ______________ ______________ moderates ______________________________

ii) ______________ ______________ moderates ______________________________

b) Where would you find each of these materials in the OPAL Reactor? Account for the use of each by reference to their properties.

i) ____

____

ii) ____

____

Question 6

Name two radioisotopes (not Mo-99/Tc-99m) produced in OPAL and state their use.

a) ____

b) ____

Question 7

In the Service Pool of the OPAL Reactor, ____________ years of spent fuel assemblies can be stored

Question 8

Cerenkov radiation, the blue glow seen in nuclear reactors where water is used as a moderator, and around some radioactive substances in water, is caused by high energy ______________________ moving through water at a rate greater than the speed of ____________________.

B. Neutron Guide Hall (NGH)

Some of the neutrons produced in the core of OPAL enter tunnels that guide them (Neutron Guides) out to the Neutron Guide Hall which is also called the __________ Institute.

Two neutron guides supply neutrons to a number of instruments:

Thermal neutron guide

This neutron guide is split into _______ beams and supplies neutrons to a total of ________ instruments. The temperature of these neutrons is about _______ ^{o}C and they are used to study the _________________ structure of materials.

Cold neutron guide

The neutrons in the cold neutron guide have been cooled by liquid _____________ to about _________ ^{o}C. There are ________ beams from this guide and there will soon be a total of _______ instruments on these beams. Cold neutrons are suitable for ___________________ and ___________________ research.

PART C

Post Tour and Extension Questions

This section is designed to be completed by students after visiting ANSTO. It consists of numerous questions on the applications of nuclear science and the aim is to consolidate and reinforce the knowledge acquired during the tour. Teachers may choose to select all or only some of the questions for their students to complete.

Question 1

Use the internet to complete this question.

a) Identify an element discovered in the last 200 years

____

b) Identify two elements discovered in the last 50 years

____

____

c) From the periodic table, account for where the most recent discoveries occurred

____

____

____

____

Question 2

Clarify the terms ‘stable isotope’ and ‘unstable isotope’

____

____

____

____

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____

Question 3

a) Identify three stable isotopes

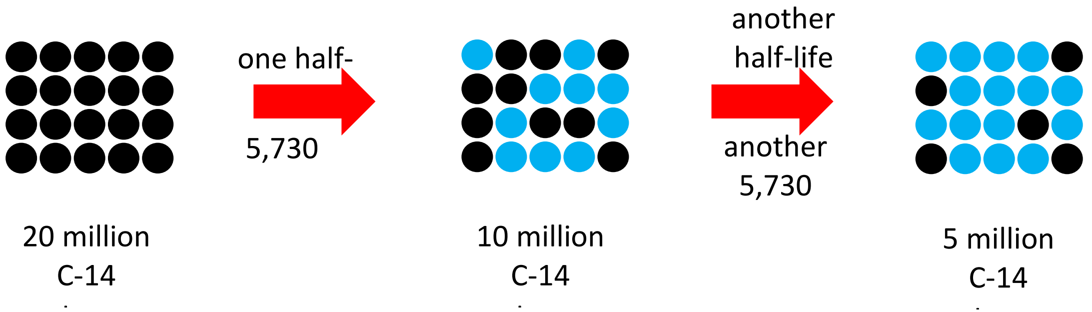
b) Identify 3 naturally occurring and 3 artificial radioisotopes (unstable isotopes)

Naturally occurring	Artificial (man-made)

Question 4

Every unstable isotope undergoes radioactive decay at a particular rate. This rate is referred to as the **half-life** of an isotope. Half-lives may be very short, just a few seconds, or very long, up to many millions of years, depending on the isotope. Carbon-14 has a half-life of 5,730 years.

Examine the following diagram and from it, explain the meaning of the term 'half-life'



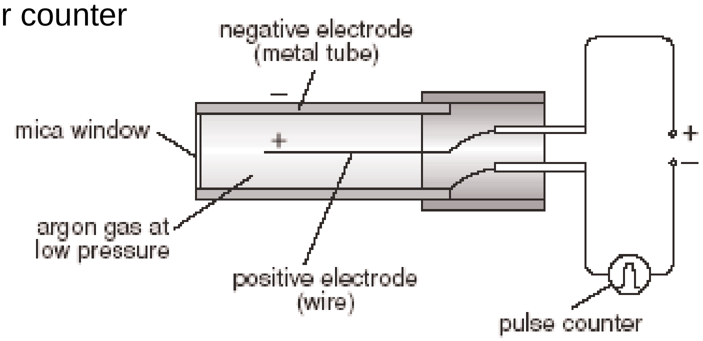
Question 5

C-14's half-life is relevant to the carbon dating technique. Explain this relevance with particular reference to the limits of reliability of the technique.

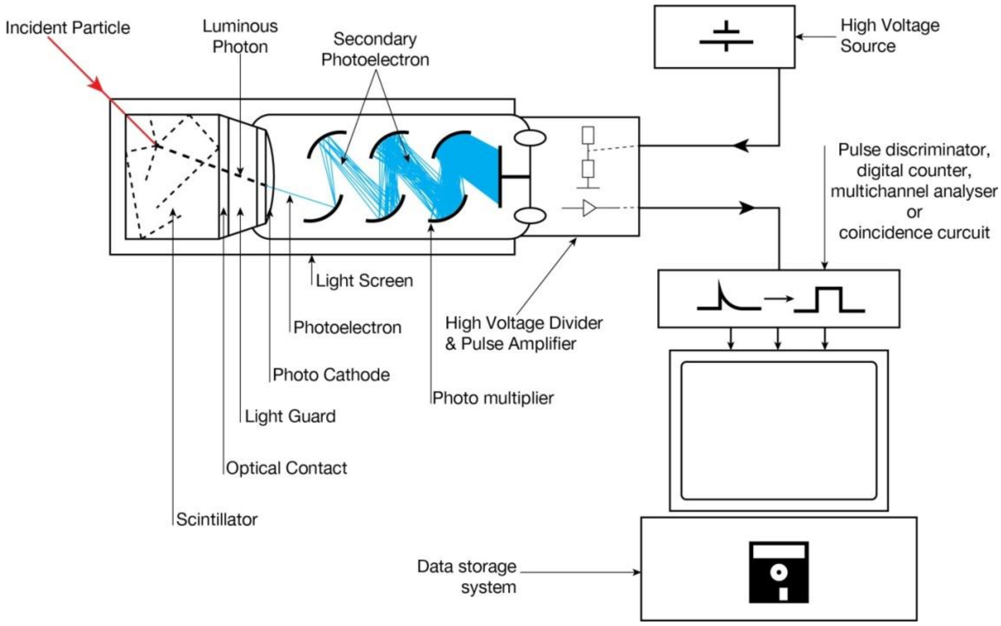
Question 6

The following diagrams show the structure of a Geiger-Muller counter and a scintillation counter. Briefly outline the principles behind the detection system in each.

a) Geiger-Muller counter



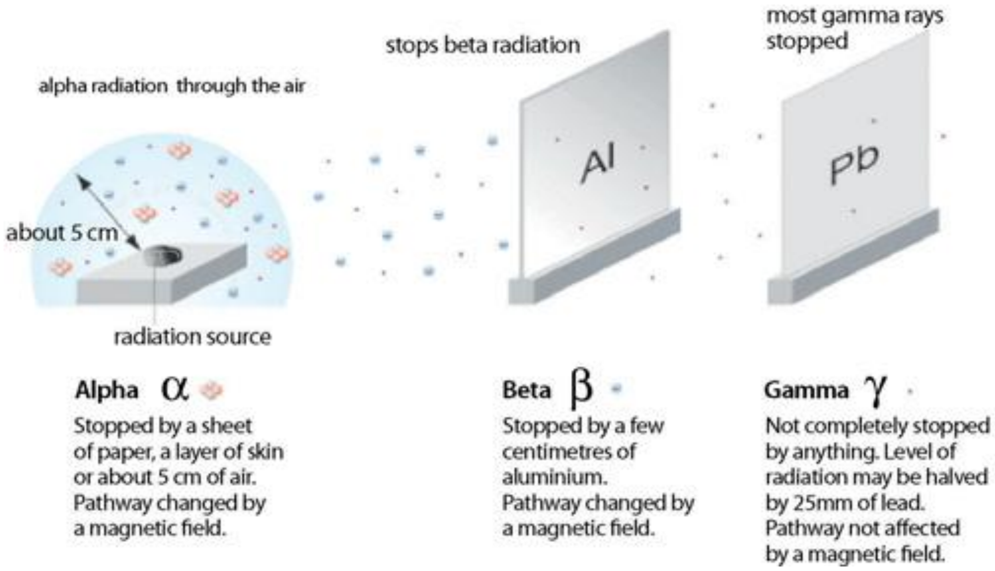
b) Scintillation counter



Schematic showing incident particles hitting a scintillating crystal, triggering the release of photons which are then converted into photoelectrons and multiplied in the photomultiplier. The photomultiplier can produce 10^6 electrons per photoelectron
(Diagram source: Harry Mustoe-Playfair of Kings College London)

Question 7

Use the diagram to describe the penetration power of the different types of radiation



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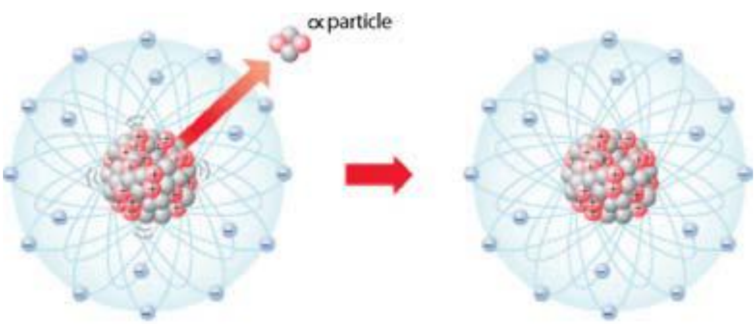
Question 8

a) The following diagram represents the alpha decay of a U-238 atom. Identify the atom produced and, using correct notation for the atoms, write the equation for the decay.



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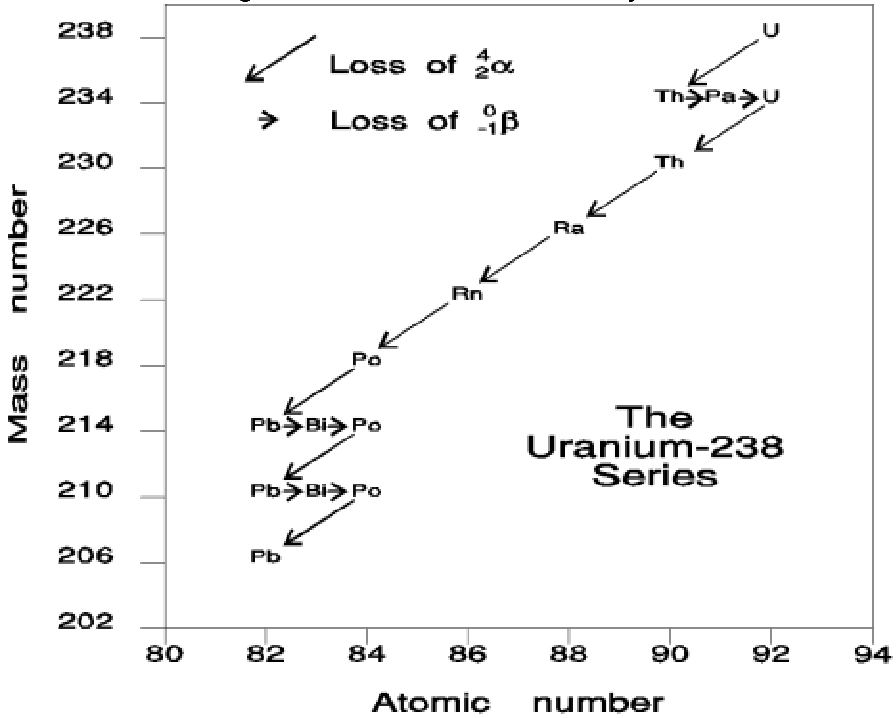
b) Strontium-90 decays to produce Yttrium-90. Deduce the type of decay it undergoes and write the equation.

Question 9

Below is a flow diagram which traces the decay series of uranium-238



Write the overall equation for the decay series from U-238 to Pb-82

Question 10

Explain the nuclear fission process

Question 11

What is meant by the term ‘fissionable material’?

Question 12

a) Write a fission reaction that produces Mo-99. (Assume 3 neutrons are released.)

____

b) Write an equation that shows the decay of Mo-99 to Tc-99m

____

c) Write an equation to show the production of another radioisotope used in medicine. You may choose I-131, Y-90, Sm-153 or another of your choosing.

____

Question 13

For each of the fission fragments shown below deduce the identity of the other fragment. In each case assume that 3 neutrons are released in the nuclear fission reaction.

a) Cs-137 ____________________

b) I-131 ____________________

c) Sr-90 ____________________

Question 14

a) What does ‘enrichment level’ refer to when talking about uranium fuel?

____

____

b) Explain the meaning of the acronyms LEU and HEU

____

____

____

____

Question 15

a) Define the term ‘transuranics’

____

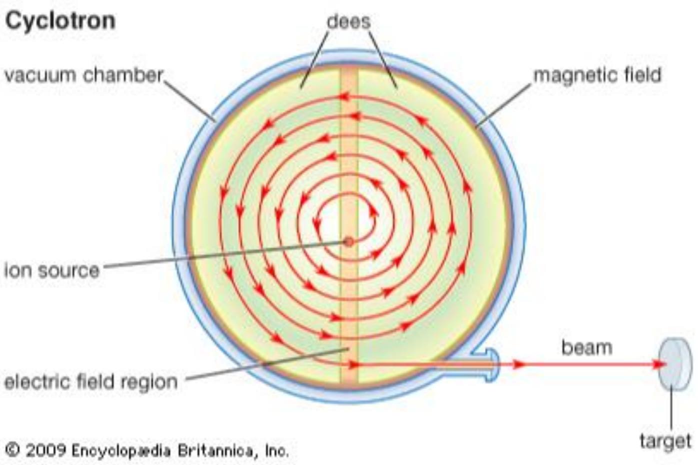
b) Describe how transuranic isotopes are produced in nuclear reactors

____

____

c) Describe how transuranic isotopes are produced in particle accelerators

Question 16



Describe the process that the cyclotron used to produce the radioactive isotope fluorine-18. Include an equation in your answer

Question 17

Contrast a nuclear reactor to a cyclotron

____

____

____

____

Question 18

Commercial radioisotopes are those produced for used in medicine, industry and/or scientific research.

a) Identify a commercial radioisotope used in industry: ______________________

b) Describe how this radioisotope is produced. Include an equation for its production

____

____

____

c) Write the equation showing this radioisotope's decay

____

d) Describe how this radioisotope is used and explain its use in terms of its properties

____

____

____

e) Outline the safety precautions required when handling, transporting or using this radioisotope

____

____

____

____

Question 19

a) Identify a commercial radioisotope used in medicine: ______________________

b) Describe how this radioisotope is produced. Include an equation for its production

c) Write the equation showing this radioisotope's decay

d) Describe how this radioisotope is used and explain its use in terms of its properties

e) Outline the safety precautions required when handling, transporting or using this radioisotope

Question 20

a) Describe the problems associated with the use of radioisotopes in society.

b) Justify the benefits of using radioisotopes in society.

Question 21

During your tour of ANSTO you will have observed the nature, practice, applications and uses of nuclear chemistry for society and the environment. You will have experienced first-hand how nuclear technologies are applied. Use the information you have gathered and staff profiles from the ANSTO website to complete the following questions.

a) Outline the role of a chemist employed at ANSTO, identifying the branch of chemistry undertaken by the chemist and explaining a chemical principle that the chemist uses.

b) Identify three different chemical occupations at ANSTO

c) Describe the role of one of the above occupations

Question 22

Describe the physical and chemical processes that need to be monitored at a nuclear reactor site.

APPENDIX A. Units for Measuring Radiation

Note: This is a very brief coverage of Radiation measurement. For further information refer to the ANSTO website and many other excellent available websites.

Most scientists in the international community, including in Australia, measure radiation using the System Internationale (SI), a uniform system of weights and measures that evolved from the metric system. In some situations however the conventional (old) system of measurement is still used.

When scientists measure radiation, they use different terms depending on whether they are discussing activity (radiation emitted) or exposure. The most important thing to understand about radiation exposure is that it is measured by what radiation does to substances, not anything particular about the radiation itself.

1) Radiation emitted from a source (Activity)

The amount of radiation being given off, or emitted, by a radioactive material is measured using the SI unit **becquerel** (Bq) or the conventional unit **curie** (Ci), named for the famed scientist Marie Curie.

The Bq or Ci is used to express the number of disintegrations of radioactive atoms in a radioactive material over a period of time. For example, one Bq is equal to one disintegration per second, whereas one Ci is equal to 37 billion (37×10^9) disintegrations per second or 37 billion (37×10^9) Bq.

Bq or Ci may be used to refer to the amount of radioactive materials released into the environment. For example, during the Chernobyl power plant accident that took place in the former Soviet Union in 1986, an estimated total of 81 million Ci of radioactive cesium (a type of radioactive material) was released.

2) Exposure 1 – Absorbed Dose

The absorbed dose (that is, the amount of energy deposited in human tissue by radiation) is measured using the SI unit **gray** (Gy) or the conventional unit **rad** (radiation absorbed dose). One Gy is equal to 100 rad.

3) Exposure 2 – Biological Risk

A person's biological risk is the risk that a person will suffer health effects from an exposure to radiation.

The **Equivalent Dose** relates the absorbed dose to the biological damage of the type of radiation by use of a radiation weighting factor.

The **Effective Dose** takes into account the different harmful effects of radiation on different types of tissue by use of a tissue weighting factor.

Both Equivalent Dose and Effective Dose are measured using the the SI unit **sievert** (Sv) or the conventional unit **rem**. As the Sievert is a very large unit, the milliSievert (mSv) or microSievert (μSv) are normally used.

1 Sievert = 1 000 milliSievert = 1 000 000 microSievert

APPENDIX B: Levels of General Background Radiation Exposure

We are all exposed to a certain level of natural background radiation each year from a variety of sources. In some parts of the world the background radiation levels are around ten times higher than those in Australia:

- General Australian background radiation dose: 1.5 mSv per year
- Cornwall, UK general background radiation dose: 7.8 mSv per year
- Average dose in Sydney Metropolitan area: 2 mSv per year

Of course, other events such as medical X-rays and scans or airplane flights will increase the dose received. Some examples of each of these are shown below:

Medical Exposures

Source of exposure	Dose in millisievert (mSv)
One dental x-ray	0.04–0.15
One chest x-ray	0.1
One mammogram	0.7
Bone scan	4.6 per treatment
Thyroid scan	2.6 per treatment
Barium meal X-ray	2.5 per treatment

Note: Actual values may be more or less depending on the exact type and number of scans

Airplane Flight Exposures

Exposure to cosmic rays during flight from … to …	Dose in millisievert (mSv)
Darwin – Perth	0.016
Darwin – Singapore	0.009
Melbourne – Johannesburg	0.071
Melbourne – Singapore – London	0.065
Sydney – Buenos Aires	0.068

Data provided by Captain Ian Getley of Qantas

Note: These are approximate figures only and will depend on altitude and time spent at that altitude