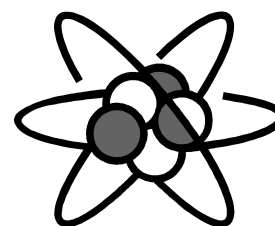
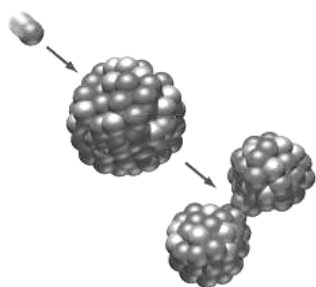


Higher Physics Homework Tutorials

Unit 3

Radiation & Matter
Version 2.0
Solutions



Tutorial 1 Waves & Radiation Revision

1. Definitions

Frequency , Number of waves per second

Wavelength , The distance from the peak of one wave to the peak of the next

Amplitude , The distance from peak to the middle of the wave

Velocity , The distance travelled per second

Refraction , The change in speed (and direction) of light as it passes from one medium to another

Diffraction , The bending of waves around an object (eg radio waves round a hill)

Interference , When two waves combine (can make result stronger or weaker)

2. For each of the following waves, calculate:

(a) 4.44×10^9 m

(b) 5.8×10^{14} Hz

(c) 28 mm

(d) 7.5×10^9 Hz

(e) 288 m

3. Copy the diagram shown into your jotter carefully.

The diagram shows a ray of light passing from air into perspex.

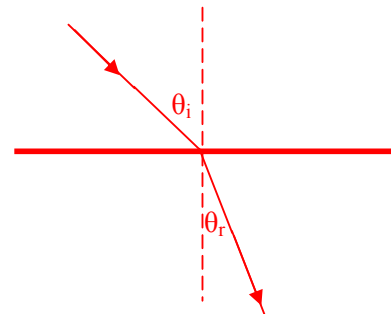
Mark on this diagram:

A normal line

Arrows indicating the direction of travel

The angle of incidence

The angle of refraction



Radiation	Shielding Material	Approx Thickness
Alpha	Paper	Normal sheet of paper
Beta	Aluminium	About 3mm
Gamma	Lead	About 3cm

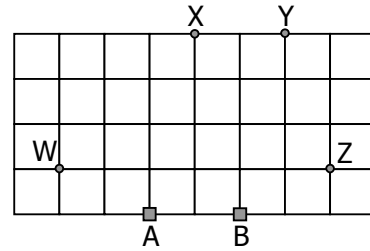


5. Goes through 3 half lives, so new activity=1000MBq

6. Has gone through two half lives, so original activity = 32,000MBq

Tutorial 2 Interference 1

- Use Pythagoras to find each individual length (eg AW and BW), then find difference.
Path Diff's- $W=1.89\text{m}$, $X=0\text{m}$, $Y=0.88\text{m}$, $Z=1.89\text{m}$



- Constructive Interference** is where two wave crests meet at the same point. They combine to increase the amplitude of the wave
Destructive interference occurs when a crest meets a trough. The interference causes the amplitude of the wave to decrease.



- For 2 marks
 - Since sources are coherent
 - Interference occurs
 - As they change position the path difference changes
 - passing points of constructive(loud) and destructive(quiet) interference

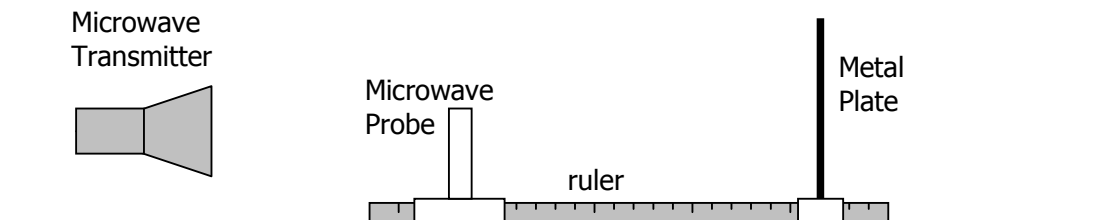
- $\lambda=0.39\text{m}$
- $0.50=2\lambda$
 $\lambda=0.25\text{ m}$
 $f=1360\text{ Hz}$

Tutorial 3 Interference 2

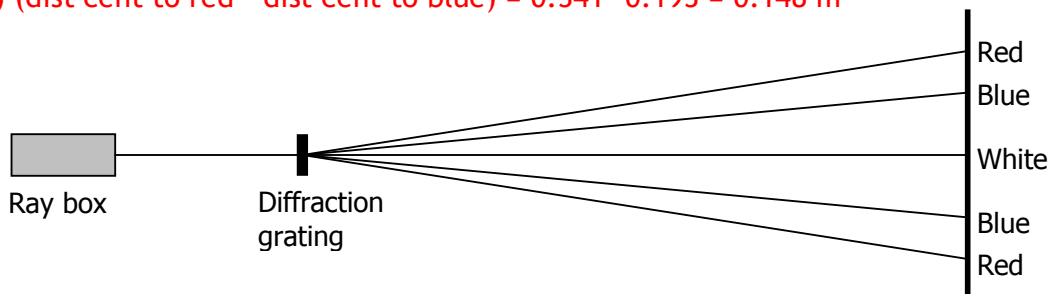
1. Lasers exhibit interference when passes through a diffraction grating. For each of the following, use the data given to determine the gap separation 'd' in metres.
 - (a) 2.0×10^{-6} m
 - (b) 2.3×10^{-5} m
 - (c) 5.3×10^{-6} m
 - (d) 3.0×10^{-6} m

2. A laser is passed through a diffraction grating which is 2 metres from a white screen. The diffraction grating used is marked as having 450 lines / mm. If the wavelength of the laser is 633nm, calculate:
 - (a) $\theta = 35^\circ$
 - (b) 1.4 m

3. For 2 marks
 - (i) move the metal plate
 - (ii) noting positions of maximum (or min) reading on the probe
 - (iii) Measure the distance the plate moved and work out the distance between two adjacent maxima (or minima)
 - (iv) The distance between two maxima is equal to half a wavelength

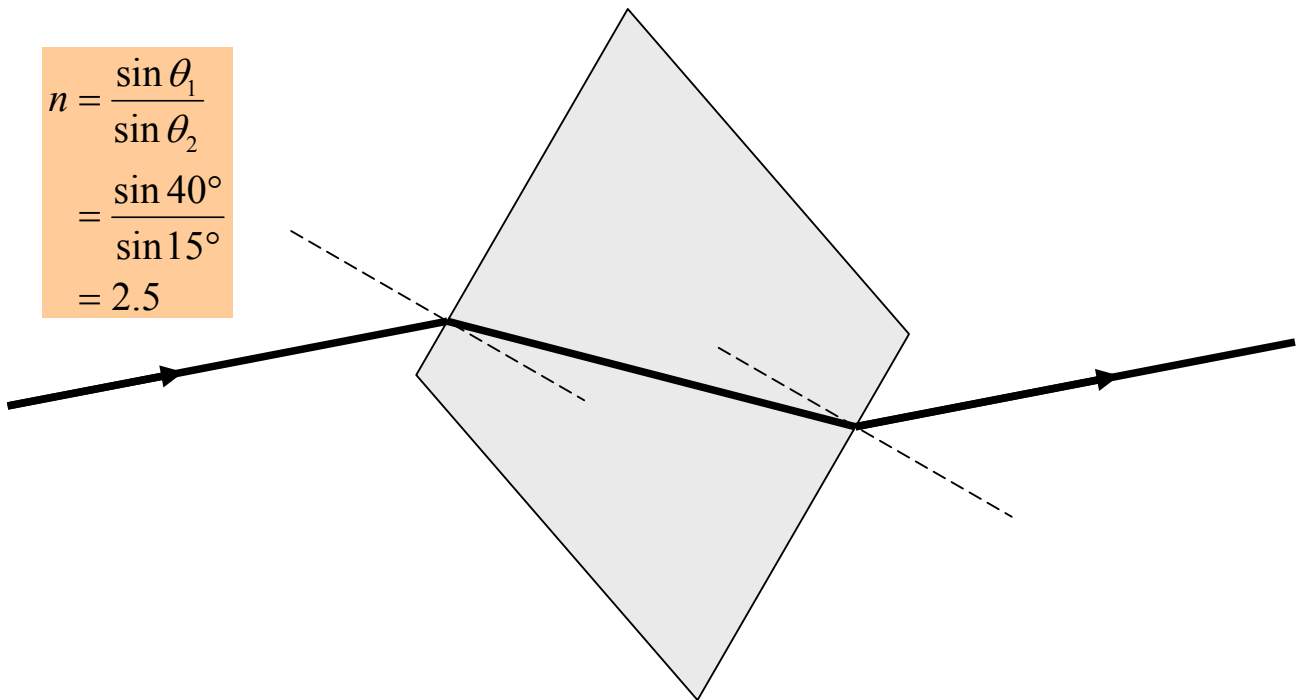
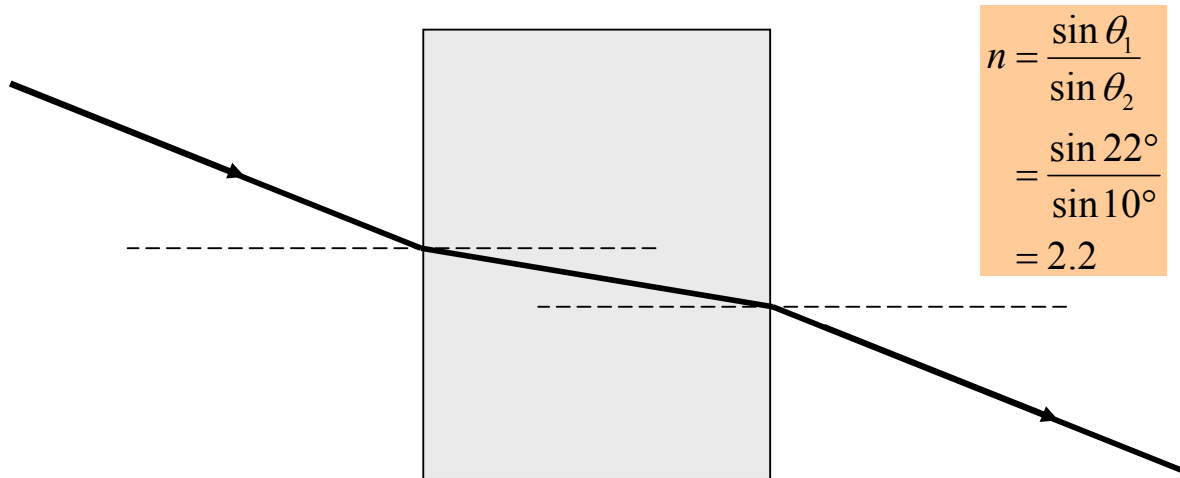


4. A ray box is set up to shine a beam of white light through a diffraction grating which has 240 lines / mm. This apparatus produces a white central maximum with a spectrum on each side. If we assume visible light ranges from 400nm to 700nm calculate:
 - (a) $\theta_{\text{blue}} = 9.7^\circ$
 - (b) $\theta_{\text{red}} = 5.5^\circ$
 - (c) (dist cent to red - dist cent to blue) = $0.341 - 0.193 = 0.148$ m



Tutorial 4 Simple Refraction

1. For each of the diagrams below, measure and note the angles of incidence and refraction and use these to calculate the refractive index of the material.

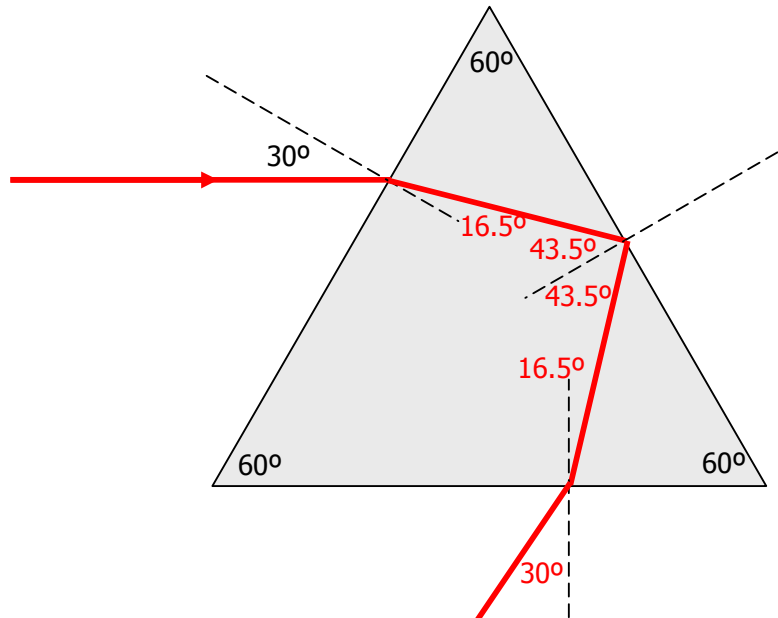


Tutorial 5 Complex Refraction

Material	Refractive Index	θ_c	Material	Refractive Index	θ_c
Air	1.00	90.0°	Ruby	1.76	34.6°
Water	1.33	48.8°	Diamond	2.42	24.4°
Pure Glass	1.50	42.8°	Flint Glass	1.61	38.4°

1. Calculate the critical angle for each of the materials in the table above.
See table above

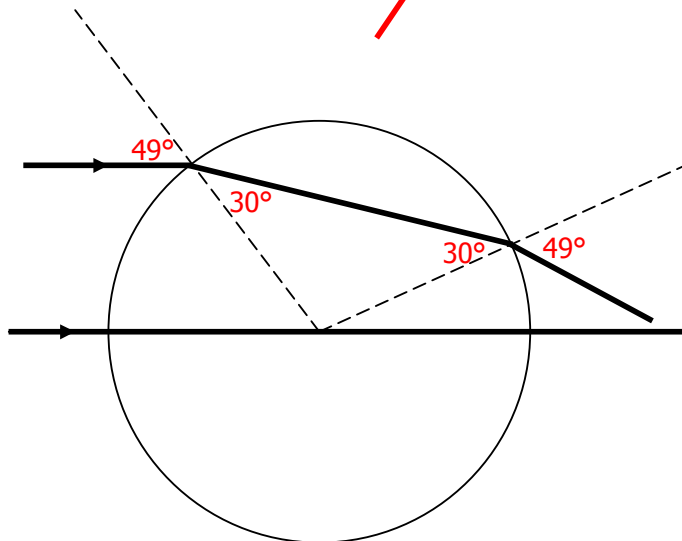
2. Light is shone into a ruby prism horizontally in the arrangement shown. Redraw the diagram (large) and show the path taken by the light through the prism until it exits. Mark the sizes of all angles of incidence, refraction and reflection.



3. Draw a circle in your jotter which is 4cm in diameter (use compasses!). This will represent a circular prism of pure glass.

Two parallel rays of light pass into it, with one ray passing straight through the centre and the other ray entering 1.5cm above it.

Show on your diagram the path of both rays of light as they pass through and out of the block.



Tutorial 6 Irradiance

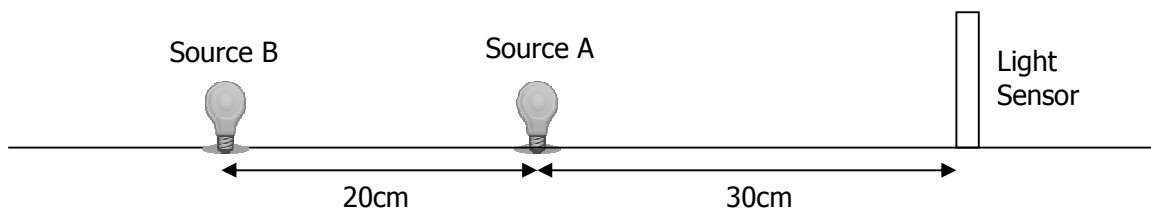
1. Calculate the irradiance in Wm^{-2} for each of the following situations:
 - (a) 633 Wm^{-2}
 - (b) 313 Wm^{-2}
 - (c) 444 Wm^{-2}
2. A PV solar panel converts 20% of the light energy falling on it into electrical energy. If the solar panel measures 1.6m by 0.8m, and is placed in sunlight with an irradiance of 800Wm^{-2} , calculate:
 - (a) 1024 W
 - (b) 205W
 - (c) 17.1 A
 - (d) $4.4 \times 10^6 \text{ J}$



3. A satellite in earth orbit ($1.496 \times 10^{11} \text{ m}$ from the sun) measures the irradiance as 1470Wm^{-2} . Calculate the irradiance at each of the following positions:
 - (a) Mercury $I = 9813 \text{ Wm}^{-2}$
 - (b) Mars $I = 628 \text{ Wm}^{-2}$
 - (c) Neptune $I = 1.61 \text{ Wm}^{-2}$
 - (d) The Voyager 1 space probe $I = 0.132 \text{ Wm}^{-2}$

4. A small point source of light is used in the experiment shown in the diagram below. With the sensor exactly 30cm from the source, the reading is 400Wm^{-2} . Another light source is placed 20cm behind the first source (50cm from the sensor). Assuming the sensor picks up the light from both sources, calculate the total irradiance detected at the sensor when the second source is activated.

$$\text{Total Reading} = 400 + (30^2/50^2) \times 400 = 400 + 144 = 544 \text{ Wm}^{-2}$$



Tutorial 7 Photoelectric Effect

Metal	$f_0(\text{hz})$	$E_w(\text{J})$	Metal	$f_0(\text{hz})$	$E_w(\text{J})$
Aluminium	9.85×10^{14}	6.53×10^{-19}	Lead	9.98×10^{14}	6.62×10^{-19}
Calcium	7.00×10^{14}	4.64×10^{-19}	Sodium	5.50×10^{14}	3.65×10^{-19}
Gold	1.23×10^{15}	8.16×10^{-19}	Zinc	1.04×10^{15}	6.88×10^{-19}

Plank's Constant = $h = 6.63 \times 10^{-34} \text{Js}$

- Calculate the threshold frequency for each of the above metals.
See table at top of page
- Calculate the energy of a photon of:
 - Red light of wavelength 680nm $= 2.93 \times 10^{-19} \text{ J}$
 - Green light of wavelength 510 nm $= 3.90 \times 10^{-19} \text{ J}$
 - Infrared radiation with a wavelength of 360 μm $= 5.53 \times 10^{-22} \text{ J}$
 - Ultraviolet radiation of wavelength 50nm $= 3.98 \times 10^{-18} \text{ J}$
 - Gamma radiation of wavelength $1 \times 10^{-12} \text{m}$ $= 1.99 \times 10^{-13} \text{ J}$
- State and explain whether or not photoelectric emission of electrons would occur in each of the following situations:
 - No emission - photon has insufficient energy
 - No emission - plate is positively charged
 - No emission - photon has insufficient energy
- If a negatively charged aluminium plate were irradiated with UV radiation with a wavelength of 250nm, photoelectric emission will occur. Calculate the maximum kinetic energy of an electron emitted from the plate.
Hence calculate the maximum velocity at which the electron could be emitted.

$f_{\text{pho}} = 1.20 \times 10^{15} \text{ Hz}$
 $E_{\text{pho}} = 7.96 \times 10^{-19} \text{ J}$
 $E_{\text{elec}} = E_{\text{pho}} - E_w = 1.43 \times 10^{-19} \text{ J}$
 $v_{\text{elec}} = 5.59 \times 10^5 \text{ ms}^{-1}$
- Explain why photoelectric emission suggests that light can act like a particle.
Since a distinct number of electrons are released (one for each photon) photoelectric effect suggests that light is made up of discrete particles which have an energy proportional to their frequency.

Tutorial 8

Emission & Absorption

The data below shows an energy level diagram for neutral hydrogen. Figures from this diagram should be used in the following question

$$W_3 = -1.30 \times 10^{-19} \text{ J}$$

$$W_2 = -2.43 \times 10^{-19} \text{ J}$$

$$W_1 = -5.44 \times 10^{-19} \text{ J}$$

$$W_0 = -21.8 \times 10^{-19} \text{ J}$$

1. From the information above, there are six possible frequencies of radiation which could be emitted from an excited hydrogen atom.

Calculate these frequencies and hence their wavelengths.

For each of the six, suggest the colour of light or type of radiation emitted

$$W_3 - W_2 \dots E = 1.13 \times 10^{-19} \text{ J} \dots f = 1.70 \times 10^{14} \text{ Hz} \dots \lambda = 1760 \text{ nm} - \text{Infrared}$$

$$W_3 - W_1 \dots E = 4.14 \times 10^{-19} \text{ J} \dots f = 6.24 \times 10^{14} \text{ Hz} \dots \lambda = 480 \text{ nm} - \text{Blue}$$

$$W_3 - W_0 \dots E = 2.05 \times 10^{-18} \text{ J} \dots f = 3.09 \times 10^{15} \text{ Hz} \dots \lambda = 97.0 \text{ nm} - \text{UV}$$

$$W_2 - W_1 \dots E = 3.01 \times 10^{-19} \text{ J} \dots f = 4.54 \times 10^{14} \text{ Hz} \dots \lambda = 661 \text{ nm} - \text{Red}$$

$$W_2 - W_0 \dots E = 1.94 \times 10^{-18} \text{ J} \dots f = 2.92 \times 10^{15} \text{ Hz} \dots \lambda = 103 \text{ nm} - \text{UV}$$

$$W_1 - W_0 \dots E = 1.64 \times 10^{-18} \text{ J} \dots f = 2.47 \times 10^{15} \text{ Hz} \dots \lambda = 122 \text{ nm} - \text{UV}$$

2. When white light is shone through hydrogen gas and then examined, some dark lines appear in the spectrum. Explain with reference to the above energy diagram why the dark lines are present.

White light would contain all visible frequencies. As photons with an energy corresponding to the energy difference between two energy levels in the atom pass through the gas, they can be absorbed by atoms causing an electron to move to a higher energy level. Since these specific frequencies of photon are absorbed, small black lines appear in the otherwise continuous spectrum. This is called an absorption spectrum.

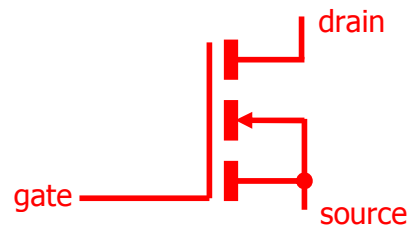
3. Explain how viewing the light from a distant star, through either a diffraction grating or a prism, allows scientists to determine the main elements present in the star.

Diffraction gratings and prisms split up light into different wavelengths such that the details of the spectrum can be analysed. The light given off by stars will exhibit an absorption spectrum corresponding to the main elements in the corona of the star. Comparing this with known elements, scientists can determine the main chemical elements present.

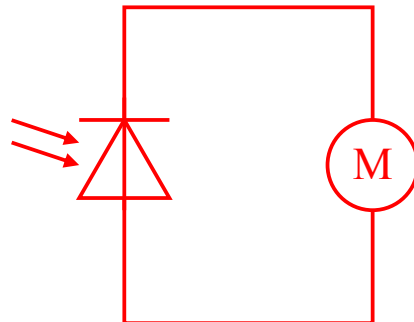
Tutorial 9 Lasers & Semiconductors

1. *Laser is an acronym, but what do the letters stand for?*
Light Amplification by Stimulated Emission of Radiation
2. *Explain the difference between spontaneous and stimulated emission of a photon.*
Spontaneous - Electron drops an energy level releasing a photon with random direction and phase. Emission occurs at a random and unpredictable time
Stimulated - Electron is stimulated to drop an energy level by another photon with the same energy passing by. Released photon is same frequency, in phase and has same direction as the stimulating photon.
3. *Semiconductors can be either P-type or N-type. Explain the meanings of these terms in terms of charge carriers.*
P-type - Doped semiconductor with excess free positive charge carriers
N-type - Doped semiconductor with excess free negative charge carriers
4. *Explain why a P-N junction diode in a reverse bias arrangement does not allow a current to flow through it.*
The potential difference across the P-N junction is such that charge carriers are drawn away from the junction of the P and N-type materials. This causes a widening of the depletion layer such and as a result charge carriers cannot move across the p-n junction, and so the diode cannot conduct.

5. *Draw the electrical symbol for a MOSFET and label the three terminals.*



6. *Draw an electrical circuit showing a photodiode in photovoltaic mode connected to an electric motor.*



Tutorial 10

Radioactive Decay Series, Fission & Fusion

For this tutorial you will need to refer to a periodic table. A simplified table is supplied at the back of this tutorial booklet. When naming elements, always give the name or symbol, atomic number and mass number.

1. ${}_{84}^{210}\text{Po} \rightarrow {}_2^4\text{He} + {}_{82}^{206}\text{Pb}$ **Lead-206**
2. ${}_{92}^{235}\text{U} \rightarrow {}_{-1}^0\text{e} + {}_{93}^{235}\text{Np}$ **Neptunium-235**
3. ${}_{93}^{237}\text{U} + {}_{-1}^0\text{e} + {}_2^4\text{He} \rightarrow {}_{94}^{241}\text{Pu}$ **Plutonium-241**
4. **Nuclear fission is where a large nucleus splits into two smaller nuclei. In doing this some mass is 'lost' and is converted to energy. The large nucleus splits when struck by a neutron. In splitting, the reaction also emits a number of neutrons, which can go on to strike other large nuclei causing them to split. This process continues and is called a chain reaction. It will not stop until all large nuclei have been split or if the neutrons are otherwise absorbed.**

Use the information about the atomic mass of the following isotopes for Q5&6

Particle	Mass(kg)	Particle	Mass(kg)
Uranium-235	3.9014×10^{-25}	Deuterium	3.3432×10^{-27}
Kryptonium-92	1.5255×10^{-25}	Tritium	5.0066×10^{-27}
Barium-141	2.3392×10^{-25}	Helium-4	6.6450×10^{-27}
neutron	1.6750×10^{-27}		

5. ${}_{92}^{235}\text{U} + {}_0^1\text{n} \rightarrow {}_{36}^{92}\text{Kr} + {}_{56}^{141}\text{Ba} + 3{}_0^1\text{n}$
Induced Fission Reaction - lost mass = 3.2×10^{-28} kg
Energy produced per reaction = 2.88×10^{-11} J

6. ${}_1^2\text{H} + {}_1^3\text{H} \rightarrow {}_2^4\text{He} + {}_0^1\text{n}$
Fusion reaction
Mass lost per reaction = 2.98×10^{-29} kg
Energy produced per reaction = 2.682×10^{-12} J

Tutorial 11 Dosimetry & Shielding

The following tables provide the radiation weighting factors for different types of radiation for use in the following tutorial.

Radiation	Weighting Factor
Alpha	20
Beta	1
Gamma	1
Fast Neutrons	10

1. Give a working definition for each of the following terms:
 - Becquerel - The number of decays in a source per second
 - Absorbed Dose - The energy of the radiation absorbed per unit mass
 - Dose Equivalent- A Measure of the biological risk of radiation exposure
 - Half Life - The time taken for the activity of a source to half
 - Half value thickness - The thickness of shielding material required to reduce the strength of radiation received by half

2. A scientist is investigating radiation and uses different types of radiation to irradiate a number of different biological samples. For each of the following calculate the absorbed dose, and hence the dose equivalent for each.
 - (a) $D=1.55 \mu\text{Gy}$... $H=1.55 \text{ Sv}$
 - (b) $D=3 \text{ mGy}$... $H=60 \text{ mSv}$
 - (c) $D=0.25 \text{ Gy}$... $H=2.5 \text{ Sv}$

3. A human being of mass 75kg works in a reactor room 6 days per year, for 3 hours each time, receiving $37\mu\text{J}$ of fast neutron radiation for each 3 hour period. Calculate:
 - (a) $D=493 \text{ nGy}$... $H=4.93 \mu\text{Sv}$... $H_{\text{rate}}=1.64 \mu\text{Svh}^{-1}$
 - (b) $D=2.96 \mu\text{Gy}$... $H=29.6 \mu\text{Sv}$... $H_{\text{rate}}=29.6 \mu\text{Sv per year or } 3.38 \text{ nSvh}^{-1}$

4. A highly radioactive source emitting gamma radiation is to be encased in steel for safety. A detector in the adjacent room currently detects 4000 counts per minute. How much steel would be required to reduce this to 500 counts per minute. The half value thickness of steel is 3.3cm.

Required Thickness = 9.9cm

5. 2 marks
 - (i) Set up source and detector - do not move these throughout experiment
 - (ii) Take unshielded count rate
 - (iii) Add shielding, take new count. Repeat with various thicknesses.
 - (iv) Draw graph and use to determine HVT. (or add shielding until count rate halves)

hydrogen 1 H	helium 2 He																										
lithium 3 Li	beryllium 4 Be	boron 5 B	carbon 6 C	nitrogen 7 N	oxygen 8 O	fluorine 9 F	neon 10 Ne																				
6.941 sodium 11 Na	9.0122 magnesium 12 Mg	10.811 aluminium 13 Al	12.011 silicon 14 Si	14.007 phosphorus 15 P	15.999 sulfur 16 S	18.998 chlorine 17 Cl	20.180 argon 18 Ar																				
22.990 potassium 19 K	24.305 calcium 20 Ca	26.982 gallium 31 Ga	28.086 germanium 32 Ge	30.974 arsenic 33 As	32.065 selenium 34 Se	35.453 bromine 35 Br	39.948 krypton 36 Kr																				
39.098 rubidium 37 Rb	40.078 strontium 38 Sr	69.723 indium 49 In	72.61 tin 50 Sn	74.922 antimony 51 Sb	78.96 tellurium 52 Te	79.904 iodine 53 I	83.80 xenon 54 Xe																				
85.468 caesium 55 Cs	87.62 barium 56 Ba	114.82 thallium 81 Tl	118.71 lead 82 Pb	121.76 bismuth 83 Bi	127.60 polonium 84 Po	126.90 astatine 85 At	131.29 radon 86 Rn																				
132.91 francium 87 Fr	137.33 radium 88 Ra																										
[223]	[226]																										
		zinc 30 Zn	copper 29 Cu	nickel 28 Ni	cobalt 27 Co	iron 26 Fe	manganese 25 Mn	chromium 24 Cr	vanadium 23 V	titanium 22 Ti	scandium 21 Sc																
		65.39 cadmium 48 Cd	63.546 silver 47 Ag	58.693 palladium 46 Pd	58.933 rhodium 45 Rh	55.845 ruthenium 44 Ru	54.938 technetium 43 Tc	51.996 molybdenum 42 Mo	50.942 niobium 41 Nb	47.867 zirconium 40 Zr	44.956 yttrium 39 Y																
		112.41 mercury 80 Hg	107.87 gold 79 Au	106.42 platinum 78 Pt	102.91 iridium 77 Ir	101.07 osmium 76 Os	[98] rhenium 75 Re	95.94 tungsten 74 W	92.906 tantalum 73 Ta	91.224 hafnium 72 Hf	88.906 lutetium 71 Lu																
		200.59 ununilium 112 Uub	196.97 unununium 111 Uuu	195.08 ununnilium 110 Uun	192.22 meitnerium 109 Mt	190.23 hassium 108 Hs	186.21 bohrium 107 Bh	183.84 seaborgium 106 Sg	180.95 dubnium 105 Db	178.49 rutherfordium 104 Rf	174.97 lawrencium 103 Lr																
		[277]	[272]	[271]	[268]	[269]	[264]	[266]	[262]	[261]	[262]																
		ununoctium 114 Uuq	207.2 ununquadium 114 Uuq																								
		[289]	[289]																								

lanthanum 57 La	cerium 58 Ce	praseodymium 59 Pr	neodymium 60 Nd	promethium 61 Pm	samarium 62 Sm	europium 63 Eu	gadolinium 64 Gd	terbium 65 Tb	dysprosium 66 Dy	holmium 67 Ho	erbium 68 Er	thulium 69 Tm	ytterbium 70 Yb
138.91 actinium 89 Ac	140.12 thorium 90 Th	140.91 protactinium 91 Pa	144.24 uranium 92 U	[145] neptunium 93 Np	150.36 plutonium 94 Pu	151.96 americium 95 Am	157.25 curium 96 Cm	158.93 berkelium 97 Bk	162.50 californium 98 Cf	164.93 einsteinium 99 Es	167.26 fermium 100 Fm	168.93 mendeleevium 101 Md	173.04 nobelium 102 No
[227]	232.04	231.04	238.03	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[259]

* Lanthanide series

** Actinide series