

Surname											Other Names										
Centre Number							Candidate Number														
Candidate Signature																					

For Examiner's Use

General Certificate of Education
June 2008
Advanced Level Examination



PHYSICS (SPECIFICATION A)

PHA6/W

Unit 6 Nuclear Instability: Medical Physics Option

Wednesday 11 June 2008 9.00 am to 10.15 am

For this paper you must have:

- a calculator
- a pencil and a ruler
- a data sheet insert.

Time allowed: 1 hour 15 minutes

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer questions in the spaces provided. Answers written in margins or on blank pages will not be marked.
- Show all your working.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information

- The maximum mark for this paper is 40. This includes up to two marks for the Quality of Written Communication.
- The marks for questions are shown in brackets.
- A *Data Sheet* is provided as a loose insert to this question paper.
- You are expected to use a calculator where appropriate.
- Questions 1(c) and 3(b)(i) should be answered in continuous prose. In these questions you will be marked on your ability to use good English, to organise information clearly and to use specialist vocabulary where appropriate.

For Examiner's Use			
Question	Mark	Question	Mark
1			
2			
3			
4			
5			
Total (Column 1) →			
Total (Column 2) →			
Quality of Written Communication			
TOTAL			
Examiner's Initials			



SECTION A: NUCLEAR INSTABILITYAnswer **all** of this question.

- 1 (a) An isotope of technetium ${}^{99}_{43}\text{Tc}^{\text{m}}$, which is in a metastable state, decays emitting only γ rays. When the isotope is placed 20 cm from a γ ray detector the count rate is 25 counts per second. The background count rate is 120 counts per minute. Calculate the count rate, in counts per second, when the detector is placed 30 cm from the isotope.

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(3 marks)

- 1 (b) (i) Calculate the approximate radius of a nucleus of ${}^{99}_{43}\text{Tc}^{\text{m}}$, given that the nuclear radius of ${}^{28}_{14}\text{Si}$ is 3.7×10^{-15} m.

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- 1 (b) (ii) State **one** method by which the nuclear radius of ${}^{28}_{14}\text{Si}$ could be determined experimentally.

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(4 marks)



- 1 (c) Explain why sources of β radiation often also produce γ rays of discrete frequencies.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer to part (c).

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(3 marks)

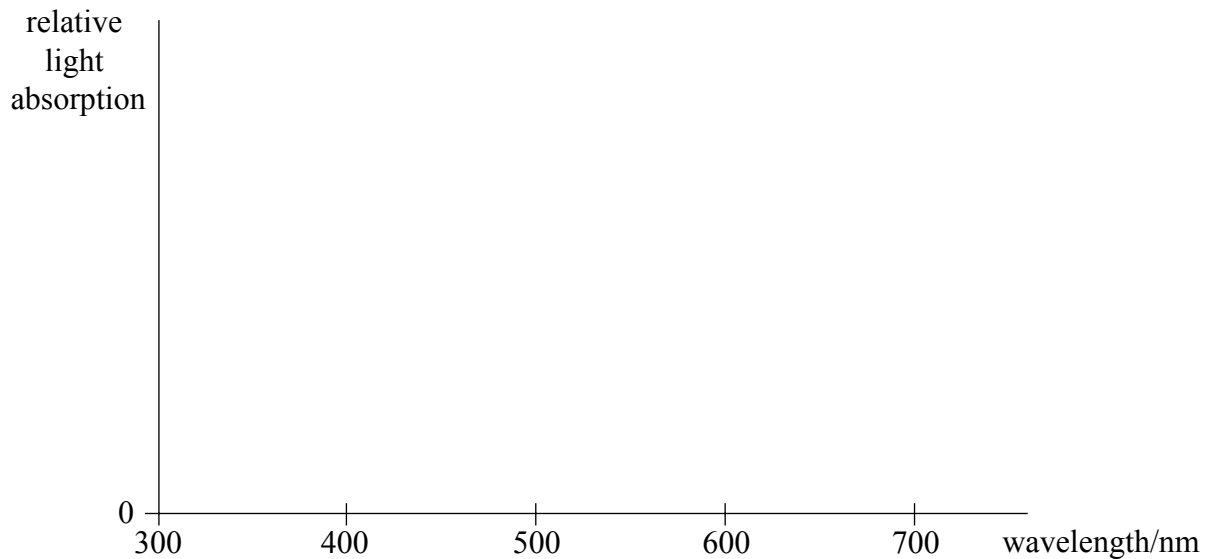
10

Turn over for the next question



SECTION B: MEDICAL PHYSICSAnswer **all** questions

- 2 The fovea in the human eye consists only of cones which have an average diameter of $1.5\ \mu\text{m}$.
- 2 (a) On the axes sketch and clearly label **three** curves to show how the response of each of the three types of cone in the fovea varies with the wavelength of light.

*(3 marks)*

- 2 (b) An eye looks directly at two point sources of light which are 8 mm apart and 40 m distant from the eye. The fovea is 19 mm behind the eye lens at the centre of the retina.
- 2 (b) (i) Calculate the separation of the two images at the fovea.

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- 2 (b) (ii) State, with a reason, whether the eye would be able to resolve the two images formed at the fovea.

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(4 marks)

7

Turn over for the next question



- 3 (a) The *threshold of hearing* is $1.0 \times 10^{-12} \text{ W m}^{-2}$. Explain what is meant by the threshold of hearing.

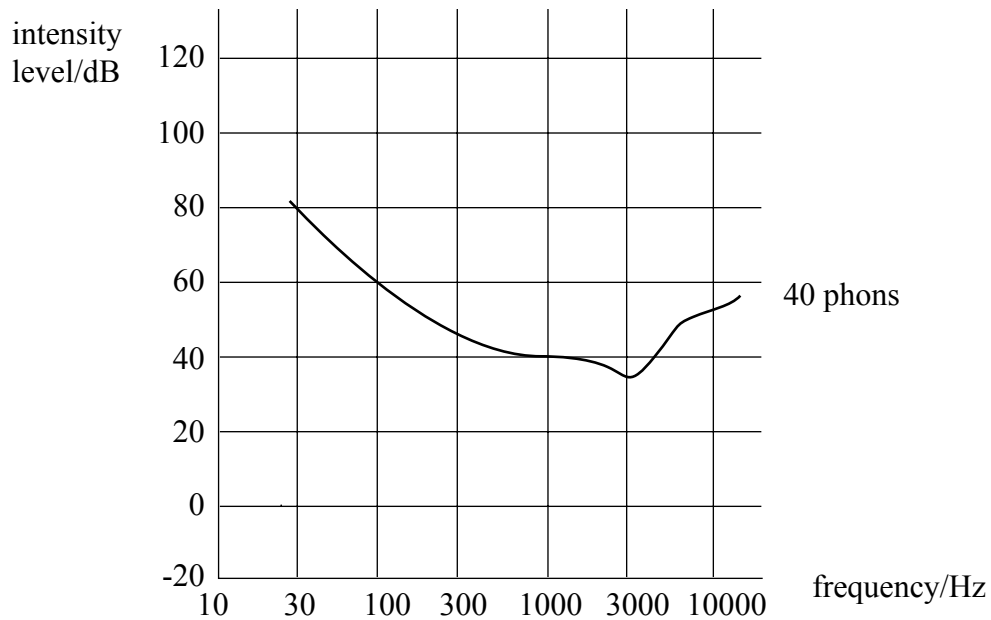
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(2 marks)

- 3 (b) The graph shows an equal loudness curve for a person with good hearing.



- 3 (b) (i) Explain how such a curve might be obtained.
You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

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- 3 (b) (ii) The ear drum of the person being tested has a cross-sectional area of 12 mm^2 . Calculate the power incident on the eardrum at a frequency of 100 Hz for the equal loudness curve shown.

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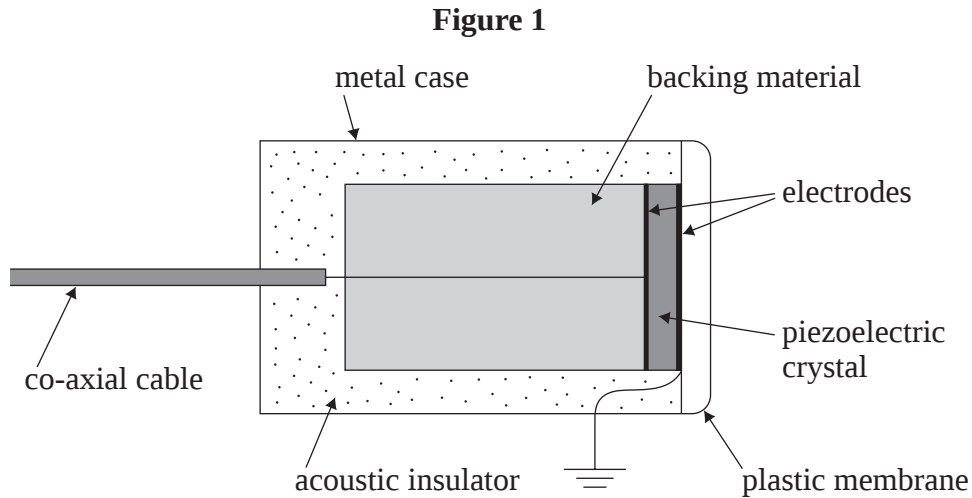
(6 marks)

8

Turn over for the next question



- 4 (a) **Figure 1** shows a cross-section through an ultrasound generator.



- 4 (a) Explain the purpose of the backing material.

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(2 marks)

- 4 (b) State the main difference between the probe used in an A-scan and that used in a B-scan.

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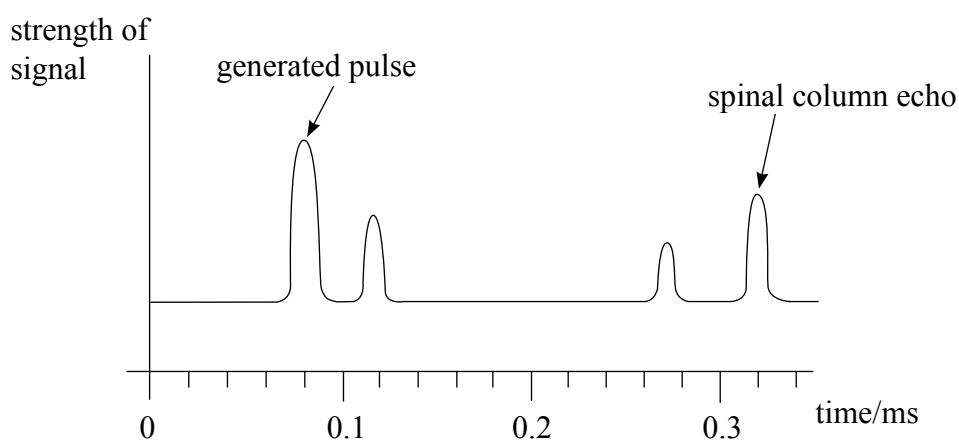
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(1 mark)



- 4 (c) **Figure 2** shows the display on an oscilloscope screen of an A-scan to find the size of an organ.

Figure 2



speed of sound in the organ = 1200 m s^{-1}

- 4 (c) (i) Calculate the diameter of the organ.

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- 4 (c) (ii) State **two** processes which reduce the strength of the reflected signal received by the probe.

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(4 marks)

5 (a) A rotating anode X-ray tube is operated at a peak voltage of 90 kV and an electron beam current of 48 mA.

5 (a) (i) Calculate the number of electrons reaching the anode each second.

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5 (a) (ii) Calculate the maximum photon energy, in J, of the X-rays produced.

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(2 marks)

5 (b) State and explain **two** ways to reduce the radiation energy absorbed by the patient when obtaining an X-ray photographic image of good quality.

First way

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Second way

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(4 marks)

Quality of Written Communication (2 marks)

6

2

END OF QUESTIONS



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PHYSICS (SPECIFICATION A)

PHA6/W

Unit 6 Nuclear Instability: Medical Physics Option

Data Sheet

Fundamental constants and values				Mechanics and Applied Physics		Fields, Waves, Quantum Phenomena	
Quantity	Symbol	Value	Units				
speed of light in vacuo	c	3.00×10^8	m s^{-1}	$v = u + at$		$g = \frac{F}{m}$	
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}	$s = \left(\frac{u+v}{2}\right)t$		$g = -\frac{GM}{r^2}$	
permittivity of free space	ϵ_0	8.85×10^{-12}	F m^{-1}	$s = ut + \frac{at^2}{2}$		$g = -\frac{\Delta V}{\Delta x}$	
charge of electron	e	1.60×10^{-19}	C	$v^2 = u^2 + 2as$		$V = -\frac{GM}{r}$	
the Planck constant	h	6.63×10^{-34}	J s	$F = \frac{\Delta(mv)}{\Delta t}$		$a = -(2\pi f)^2 x$	
gravitational constant	G	6.67×10^{-11}	$\text{N m}^2 \text{kg}^{-2}$	$P = Fv$		$v = \pm 2\pi f \sqrt{A^2 - x^2}$	
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}	$\text{efficiency} = \frac{\text{power output}}{\text{power input}}$		$x = A \cos 2\pi ft$	
molar gas constant	R	8.31	$\text{J K}^{-1} \text{mol}^{-1}$	$\omega = \frac{v}{r} = 2\pi f$		$T = 2\pi \sqrt{\frac{m}{k}}$	
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}	$a = \frac{v^2}{r} = r\omega^2$		$T = 2\pi \sqrt{\frac{L}{g}}$	
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$	$I = \sum mr^2$		$\lambda = \frac{\omega s}{D}$	
the Wien constant	a	2.90×10^{-3}	m K	$E_k = \frac{1}{2} I \omega^2$		$d \sin \theta = n\lambda$	
electron rest mass	m_e	9.11×10^{-31}	kg	$\omega_2 = \omega_1 + at$		$\theta \approx \frac{\lambda}{D}$	
(equivalent to $5.5 \times 10^{-4} \text{u}$)				$\theta = \omega_1 t + \frac{1}{2} at^2$		${}_1n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$	
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}	$\omega_2^2 = \omega_1^2 + 2a\theta$		${}_1n_2 = \frac{n_2}{n_1}$	
proton rest mass	m_p	1.67×10^{-27}	kg	$\theta = \frac{1}{2} (\omega_1 + \omega_2)t$		$\sin \theta_c = \frac{1}{n}$	
(equivalent to 1.00728u)				$T = Ia$		$E = hf$	
proton charge/mass ratio	e/m_p	9.58×10^7	C kg^{-1}	$\text{angular momentum} = I\omega$		$hf = \phi + E_k$	
neutron rest mass	m_n	1.67×10^{-27}	kg	$W = T\theta$		$hf = E_1 - E_2$	
(equivalent to 1.00867u)				$P = T\omega$		$\lambda = \frac{h}{p} = \frac{h}{mv}$	
gravitational field strength	g	9.81	N kg^{-1}	$\text{angular impulse} = \text{change of angular momentum} = Tt$		$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$	
acceleration due to gravity	g	9.81	m s^{-2}	$\Delta Q = \Delta U + \Delta W$		Electricity	
atomic mass unit	u	1.661×10^{-27}	kg	$\Delta W = p\Delta V$		$\epsilon = \frac{E}{Q}$	
(1u is equivalent to 931.3 MeV)				$pV^\gamma = \text{constant}$		$\epsilon = I(R + r)$	
Fundamental particles				$\text{work done per cycle} = \text{area of loop}$		$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$	
Class	Name	Symbol	Rest energy /MeV	$\text{input power} = \text{calorific value} \times \text{fuel flow rate}$		$R_T = R_1 + R_2 + R_3 + \dots$	
photon	photon	γ	0	$\text{indicated power as (area of } p-V \text{ loop)} \times (\text{no. of cycles/s}) \times (\text{no. of cylinders})$		$P = I^2 R$	
lepton	neutrino	ν_e	0	$\text{friction power} = \text{indicated power} - \text{brake power}$		$E = \frac{F}{Q} = \frac{V}{d}$	
		ν_μ	0	$\text{efficiency} = \frac{W}{Q_{\text{in}}} = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}}$		$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$	
	electron	$e^\pm$	0.510999	$\text{maximum possible efficiency} = \frac{T_H - T_C}{T_H}$		$E = \frac{1}{2} QV$	
	muon	$\mu^\pm$	105.659			$F = BIl$	
mesons	pion	$\pi^\pm$	139.576			$F = BQv$	
		π^0	134.972			$Q = Q_0 e^{-t/RC}$	
	kaon	$K^\pm$	493.821			$\phi = BA$	
		K^0	497.762				
baryons	proton	p	938.257				
	neutron	n	939.551				
Properties of quarks							
Type	Charge	Baryon number	Strangeness				
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0				
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0				
s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1				
Geometrical equations							
arc length = $r\theta$							
circumference of circle = $2\pi r$							
area of circle = πr^2							
area of cylinder = $2\pi rh$							
volume of cylinder = $\pi r^2 h$							
area of sphere = $4\pi r^2$							
volume of sphere = $\frac{4}{3}\pi r^3$							

$$\text{magnitude of induced emf} = N \frac{\Delta\Phi}{\Delta t}$$

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

Mechanical and Thermal Properties

$$\text{the Young modulus} = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F}{A} \frac{l}{e}$$

$$\text{energy stored} = \frac{1}{2} Fe$$

$$\Delta Q = mc \Delta\theta$$

$$\Delta Q = ml$$

$$pV = \frac{1}{3} Nmc^2$$

$$\frac{1}{2} mc^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$$

Nuclear Physics and Turning Points in Physics

$$\text{force} = \frac{eV_p}{d}$$

$$\text{force} = Bev$$

$$\text{radius of curvature} = \frac{mv}{Be}$$

$$\frac{eV}{d} = mg$$

$$\text{work done} = eV$$

$$F = 6\pi\eta rv$$

$$I = k \frac{I_0}{x^2}$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$\lambda = \frac{h}{\sqrt{2}meV}$$

$$N = N_0 e^{-\lambda t}$$

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

$$R = r_0 A^{\frac{1}{3}}$$

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

$$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$$

$$t = \frac{t_0}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

Astrophysics and Medical Physics

Body	Mass/kg	Mean radius/m
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Sun	2.00×10^{30}	7.00×10^8
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Earth	6.00×10^{24}	6.40×10^6
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$$1 \text{ astronomical unit} = 1.50 \times 10^{11} \text{ m}$$

$$1 \text{ parsec} = 206265 \text{ AU} = 3.08 \times 10^{16} \text{ m} = 3.26 \text{ ly}$$

$$1 \text{ light year} = 9.45 \times 10^{15} \text{ m}$$

$$\text{Hubble constant (H)} = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$$

$$M = \frac{f_o}{f_e}$$

$$m - M = 5 \log \frac{d}{10}$$

$$\lambda_{\text{max}} T = \text{constant} = 0.0029 \text{ m K}$$

$$v = Hd$$

$$P = \sigma AT^4$$

$$\frac{\Delta f}{f} = \frac{v}{c}$$

$$\frac{\Delta \lambda}{\lambda} = -\frac{v}{c}$$

$$R_s \approx \frac{2GM}{c^2}$$

Medical Physics

$$\text{power} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \text{ and } m = \frac{v}{u}$$

$$\text{intensity level} = 10 \log \frac{I}{I_0}$$

$$I = I_0 e^{-\mu x}$$

$$\mu_m = \frac{\mu}{\rho}$$

Electronics

Resistors

Preferred values for resistors (E24)
Series: 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0 3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1 ohms
and multiples that are ten times greater

$$Z = \frac{V_{\text{rms}}}{I_{\text{rms}}}$$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

$$C_T = C_1 + C_2 + C_3 + \dots$$

$$X_C = \frac{1}{2\pi fC}$$

Alternating Currents

$$f = \frac{1}{T}$$

Operational amplifier

$$G = \frac{V_{\text{out}}}{V_{\text{in}}} \quad \text{voltage gain}$$

$$G = -\frac{R_f}{R_1} \quad \text{inverting}$$

$$G = 1 + \frac{R_f}{R_1} \quad \text{non-inverting}$$

$$V_{\text{out}} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right) \quad \text{summing}$$