

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)
Unit 7 Nuclear Instability: Applied Physics Option

PHA7/W

Wednesday 11 June 2008 9.00 am to 10.15 am

<p>For this paper you must have:</p> <ul style="list-style-type: none"> • a pencil and a ruler • a calculator • a data sheet insert.
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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 the 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 4(a) 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 INSTABILITY

Answer **all** of this question.

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

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

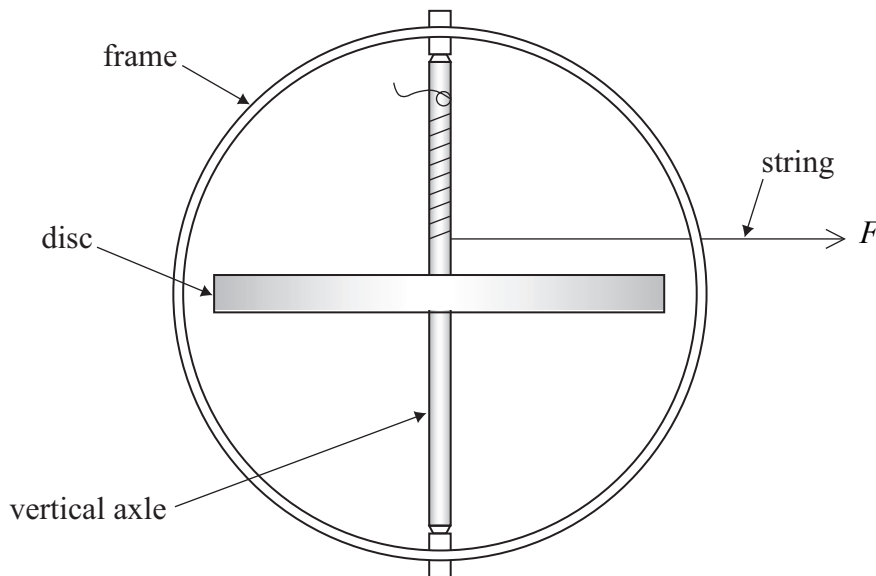
Turn over ▶



SECTION B: APPLIED PHYSICS

Answer **all** questions

- 2 **Figure 1** shows a small gyroscope. A heavy disc is mounted on an axle which is supported by a rigid circular frame. A length of string is wrapped around the axle and is pulled with a constant force, accelerating the disc until the string is completely unwrapped and falls away from the axle. With the disc rotating at high speed the properties of a gyroscope can be demonstrated.

Figure 1

moment of inertia of the flywheel and axle about its axis = $1.8 \times 10^{-4} \text{ kg m}^2$
 axle diameter = 4.0 mm

- 2 (a) The string is wrapped 30 times around the axle. Measurements show that it takes 2.1 s for the string to unwind from rest.
- 2 (a) (i) Show that the angular acceleration of the disc and axle is 85 rad s^{-2} .

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- 2 (a) (ii) The maximum angular speed is reached when the string leaves the axle. Calculate this speed.

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- 2 (a) (iii) Neglecting friction at the bearings, calculate the pulling force F .

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(5 marks)

- 2 (b) After the string left the axle it took 72 s for the disc to come to rest. This shows that there is a small frictional torque acting at the bearings. Calculate this frictional torque.

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(1 mark)

6

Turn over for the next question

Turn over ▶



- 3 (a) (i) Explain what is meant by the *adiabatic compression* of a gas.

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- 3 (a) (ii) Explain why the compression stroke of a Diesel engine can be considered to be adiabatic.

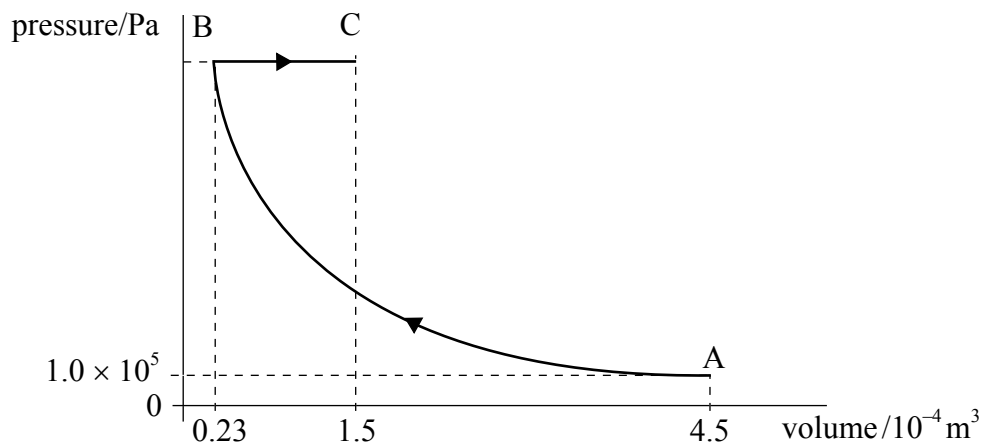
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(2 marks)

- 3 (b) **Figure 2** shows part of an ideal Diesel engine cycle in which a constant mass of air is compressed adiabatically, $A \rightarrow B$, and is then heated at constant pressure, $B \rightarrow C$.
adiabatic index, γ , for air = 1.4

Figure 2



- 3 (b) (i) Calculate the pressure at B.

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3 (b) (ii) Apply the first law of thermodynamics to complete the gaps in the table.

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	$\Delta W/\text{J}$	$\Delta Q/\text{J}$	$\Delta U/\text{J}$
A \rightarrow B	-255		
B \rightarrow C		2860	

(5 marks)

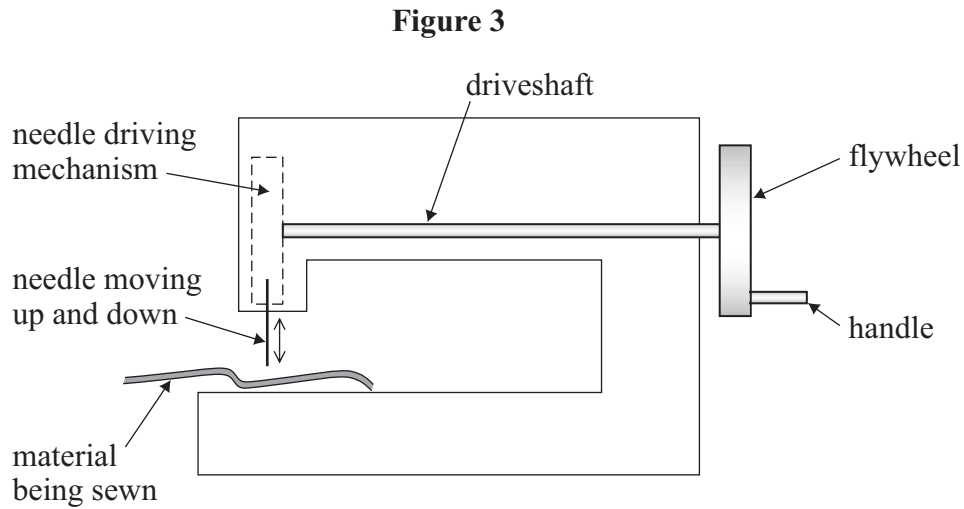
7

Turn over for the next question

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- 4 **Figure 3** shows the basic drive system of a hand-driven sewing machine. During one revolution the torque on the driveshaft varies because of the varying force on the needle when a stitch is made.



- 4 (a) Explain the function of the flywheel.

You may be awarded marks for the quality of written communication in your answer.

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(2 marks)

- 4 (b) The moment of inertia of the flywheel about its axis is $3.7 \times 10^{-3} \text{ kg m}^2$. Before a stitch is made the angular speed of the driveshaft is 14 rad s^{-1} . Calculate the rotational kinetic energy of the flywheel when rotating at this speed.

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(1 mark)



- 4 (c) After the handle is released a stitch is made, and the kinetic energy of the flywheel is reduced by 0.082 J.

Calculate

- 4 (c) (i) the angular speed of the flywheel immediately after the stitch is made,

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- 4 (c) (ii) the angular impulse acting on the flywheel during the making of a stitch.

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(3 marks)

6

Turn over for the next question

Turn over ▶



5 'Atmospheric' engines were once used to pump water out of mines. These engines operated on the following cycle:

- the weight of the pump rod raised the piston and at the same time steam was admitted to the cylinder (see **Figure 4**.)
- the steam valve was closed and the water valve opened, allowing a jet of cold water into the cylinder to condense the steam. This created a partial vacuum. Atmospheric pressure forced the piston down, lifting the pump rod and raising water from the mine (see **Figure 5**.)
- when the piston was at the bottom of its stroke, the drain valve was opened to let the condensed steam and cooling water out of the cylinder.

Figure 4

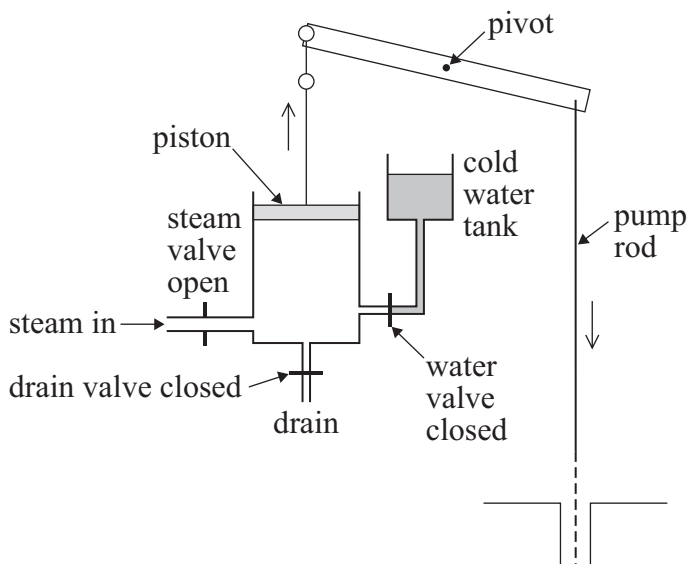
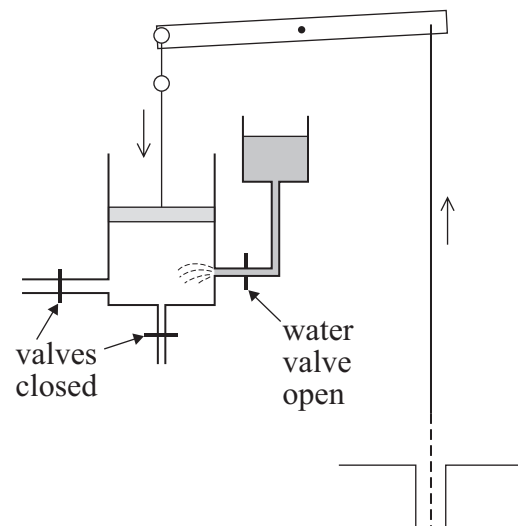
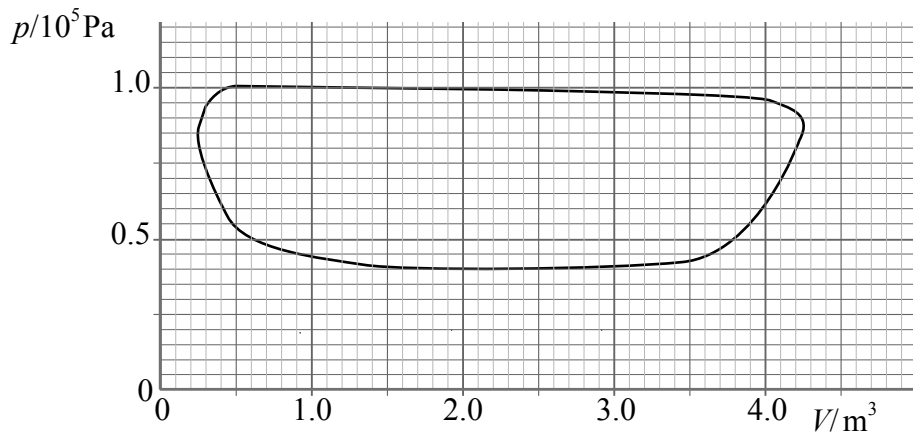


Figure 5



The $p - V$ diagram for one particular atmospheric engine is shown in **Figure 6**.

Figure 6



5 (a) (i) Use Figure 6 to determine the indicated work done by the engine in one cycle.

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5 (a) (ii) It took 6.0 seconds for the engine to complete one cycle. Calculate the indicated power of the engine.

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(4 marks)

5 (b) In each cycle, a mass of 7600 kg of water was raised a height of 1.8 m. Determine for this engine.

5 (b) (i) the output power,

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Question 5 continues on the next page

Turn over ▶



5 (b) (i) the mechanical efficiency.

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(2 marks)

5 (c) The temperature of the steam was 103°C (376 K) and the cooling water was at 15°C (288 K).

5 (c) (i) Calculate the maximum theoretical efficiency of a heat engine operating between these temperatures.

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5 (c) (ii) The actual overall efficiency of the engine was less than 1%. Suggest **two** reasons why the efficiency of the engine was so very low.

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(3 marks)

9

Quality of Written Communication (2 marks)

2

END OF QUESTIONS



PHYSICS (SPECIFICATION A)

PHA7W

Unit 7 Nuclear Instability: Applied 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	$P = Fv$		$a = -(2\pi f)^2 x$	
gravitational constant	G	6.67×10^{-11}	$\text{N m}^2 \text{kg}^{-2}$	$\text{efficiency} = \frac{\text{power output}}{\text{power input}}$		$v = \pm 2\pi f \sqrt{A^2 - x^2}$	
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}	$\omega = \frac{v}{r} = 2\pi f$		$x = A \cos 2\pi ft$	
molar gas constant	R	8.31	$\text{J K}^{-1} \text{mol}^{-1}$	$a = \frac{v^2}{r} = r\omega^2$		$T = 2\pi\sqrt{\frac{m}{k}}$	
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}	$I = \sum mr^2$		$T = 2\pi\sqrt{\frac{l}{g}}$	
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$	$E_k = \frac{1}{2} I\omega^2$		$\lambda = \frac{\omega s}{D}$	
the Wien constant	a	2.90×10^{-3}	m K	$\omega_2 = \omega_1 + at$		$d \sin \theta = n\lambda$	
electron rest mass	m_e	9.11×10^{-31}	kg	$\theta = \omega_1 t + \frac{1}{2} at^2$		$\theta \approx \frac{\lambda}{D}$	
(equivalent to $5.5 \times 10^{-4} \text{u}$)				$\omega_2^2 = \omega_1^2 + 2a\theta$		${}^1n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$	
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}	$\theta = \frac{1}{2} (\omega_1 + \omega_2)t$		${}^1n_2 = \frac{n_2}{n_1}$	
proton rest mass	m_p	1.67×10^{-27}	kg	$T = Ia$		$\sin \theta_c = \frac{1}{n}$	
(equivalent to 1.00728u)				$\text{angular momentum} = I\omega$		$E = hf$	
proton charge/mass ratio	e/m_p	9.58×10^7	C kg^{-1}	$W = T\theta$		$hf = \phi + E_k$	
neutron rest mass	m_n	1.67×10^{-27}	kg	$P = T\omega$		$hf = E_1 - E_2$	
(equivalent to 1.00867u)				$\text{angular impulse} = \text{change of angular momentum} = Tt$		$\lambda = \frac{h}{p} = \frac{h}{mv}$	
gravitational field strength	g	9.81	N kg^{-1}	$\Delta Q = \Delta U + \Delta W$		$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$	
acceleration due to gravity	g	9.81	m s^{-2}	$\Delta W = p\Delta V$		Electricity	
atomic mass unit	u	1.661×10^{-27}	kg	$pV^\gamma = \text{constant}$		$\epsilon = \frac{E}{Q}$	
(1u is equivalent to 931.3 MeV)				$\text{work done per cycle} = \text{area of loop}$		$\epsilon = I(R + r)$	
Fundamental particles				$\text{input power} = \text{calorific value} \times \text{fuel flow rate}$		$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$	
<i>Class</i>	<i>Name</i>	<i>Symbol</i>	<i>Rest energy</i>	$\text{indicated power as (area of } p-V \text{ loop)} \times (\text{no. of cycles/s}) \times (\text{no. of cylinders})$		$R_T = R_1 + R_2 + R_3 + \dots$	
			/MeV	$\text{friction power} = \text{indicated power} - \text{brake power}$		$P = I^2 R$	
photon	photon	γ	0	$\text{efficiency} = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$		$E = \frac{F}{Q} = \frac{V}{d}$	
lepton	neutrino	ν_e	0	$\text{maximum possible efficiency} = \frac{T_H - T_C}{T_H}$		$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$	
		ν_μ	0			$E = \frac{1}{2} QV$	
	electron	e^\pm	0.510999			$F = BI$	
	muon	μ^\pm	105.659			$F = BQv$	
mesons	pion	π^\pm	139.576			$Q = Q_0 e^{-t/RC}$	
		π^0	134.972			$\Phi = BA$	
	kaon	K^\pm	493.821				
		K^0	497.762				
baryons	proton	p	938.257				
	neutron	n	939.551				
Properties of quarks							
<i>Type</i>	<i>Charge</i>	<i>Baryon number</i>	<i>Strangeness</i>				
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 = $\frac{4}{3}\pi r^3$							

Turn over ►

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

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

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

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
Sun	2.00×10^{30}	7.00×10^8
Earth	6.00×10^{24}	6.40×10^6

$$1 \text{ astronomical unit} = 1.50 \times 10^{11} \text{ m}$$

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

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

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

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

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

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

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

$$v = Hd$$

$$P = \sigma AT^4$$

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

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

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

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

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

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

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

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