TOPIC 1 Physical Quantities & Units

Units

1 The e.m.f. E_b of a battery is given by $E_b = P/I$ where P is the power dissipated when a current I flows. The e.m.f. E_c induced in a coil by a changing magnetic flux is equal to the rate of change of flux, $E_c = d\Phi/dt$

Which of the following is a unit for magnetic flux?

A ms^{-1} A
B ms^{-2} A^{-1}
C kg m^2 s^{-2} A
D kg ms^2 A^{-1}
E kg m^2 s^{-2} A^{-1} J79/II/25; N79/II/17; J90/I/3

2 The experimental measurement of the heat capacity C of a solid as a function of temperature T is to be fitted to the expression

$$C = \alpha T + \beta T^3$$

What are possible units of α and β?

	α	β
A	J	J K^{-2}
B	J K^2	J
C	J K	J K^3
D	J K^{-2}	J K^{-4}
E	J	J

J79/II/29

3 At temperatures close to 0 K, the specific heat capacity of a particular solid is given by $c = aT^3$, where T is the thermodynamic temperature and a is a constant characteristic of the solid. What are the units of constant a expressed in SI based units?

A m^2 s^{-2} K^{-1}
B m^2 s^{-2} K^{-3}
C m^2 s^{-2} K^{-4}
D kg m^2 s^{-2} K^{-3}
E kg m^2 s^{-2} K^{-4} N82/II/29

4 In terms of the kilogram (kg), metre (m), second (s), and kelvin (K), what are the base units of specific heat capacity?

A ms^{-2} K^{-1}
B ms^{-1} K^{-1}
C m^2 s^{-2} K^{-1}
D m^2 s^{-1} K^{-1}
E kg^{-1} m^2 K^{-1} J83/II/28; J93/I/2

*5 The behaviour of many real gases deviates from $pV_m = RT$ but can be represented quite closely over certain ranges of temperature and pressure by an equation of the form

$$\left(p + \frac{a}{V_m^2}\right)(V_m - b) = RT$$

in which the values of a and b are characteristic of the particular gas.

What are the units of a and b?

	a	b
A	Pa m^{-6} mol^2	m^3 mol^{-1}
B	Pa m^6 mol^{-2}	m^{-3} mol
C	Pa m^{-6} mol^2	m^{-3} mol^{-1}
D	Pa m^6 mol^{-2}	m^3 mol^{-1}
E	none because they are dimensionless constant.	

J84/II/27

*6 In which one of the following pairs of electrical units are the units **not** equivalent?

A Wb m^{-2}; T
B J s^{-1}; W
C J C^{-1}; V
D A s^{-1}; C
E C V^{-1}; F J87/I/2

*7 An alternative form of the unit of resistance, the ohm (Ω), is V A^{-1}.

Which of the following examples shows a similar correct alternative form of unit?

	unit	*alternative form*
A	coulomb (C)	A s^{-1}
B	farad (F)	V C^{-1}
C	pascal (Pa)	N m^{-2}
D	volt (V)	J C
E	watt (W)	J s

J91/I/1

8 Which expression could be correct for the velocity v of ocean waves in terms of ρ the density of sea-water, g the acceleration of free fall, h the depth of the ocean and λ the wavelength?

A $\sqrt{g\lambda}$ **B** $\sqrt{\frac{g}{h}}$ **C** $\sqrt{\rho g h}$ **D** $\sqrt{\frac{g}{\rho}}$

N91/I/2; N96/I/2

9 Which of the following quantities has a unit that can be expressed in terms of just two different SI base units?

A area
B charge
C current
D force
E resistance

J92/I/2

10 The base units of the SI system include those of

mass, kg; length, m; time, s; electric current, A.

Which base units would be needed to express the SI unit of potential difference (the volt)?

A m and A only
B s and A only
C m, s, and A only
D kg, m, s, and A N93/I/1; J98/I/3

11 If p is the momentum of an object of mass m, the expression $\frac{p^2}{m}$ has base units identical to

- **A** energy.
- **B** force.
- **C** power.
- **D** velocity.

N94/I/1; J97/I/1

12 Which expression does **not** have the second (s) as its base unit?

- **A** $\frac{1}{\text{frequency}}$
- **B** capacitance × resistance
- **C** $\sqrt{\text{length} \div \text{acceleration}}$
- **D** mass ÷ spring constant

J95/I/1

13 The energy of a photon of light of frequency f is given by hf, where h is the Planck constant.

What are the base units of h?

- **A** kg m s^{-1}
- **B** kg m^2 s^{-1}
- **C** kg m^2 s^{-2}
- **D** kg m^2 s^{-3}

N95/I/1

14 Which list of SI units contains only base units?

- **A** kelvin, metre, mole, ampere, kilogram
- **B** kilogram, metre, second, ohm, mole
- **C** kilogram, newton, metre, ampere, ohm
- **D** newton, kelvin, second, volt, mole

J96/I/1

15 Which of the following is a unit of pressure?

- **A** kg m s^{-1}
- **B** kg m^{-1} s^{-2}
- **C** kg m^2 s^{-2}
- **D** kg m^{-2} s^{-1}

N98/I/1

16 Four physical quantities P, Q, R and S are related by the equation $P = Q - RS$.

Which statement must be correct for the equation to be homogeneous?

- **A** P, Q, R and S all have the same units.
- **B** P, Q, R and S are all scalar quantities.
- **C** The product RS has the same units as P and Q.
- **D** The product RS is numerically equal to $(Q - P)$.

N99/I/1

17 A recent theory suggests that time may be quantised, and that the quantum, or elementary amount, of time T is given by the equation $T = h/(m_p c^2)$, where h is the Planck constant, m_p is the proton mass and c is the speed of light. Confirm that this equation is dimensionally consistent. N80/I/1

18 The dimensions of torque are the same as those of energy. Explain why it would nevertheless be inappropriate to measure torque in joules. State an appropriate unit. J85/II/1

19 The drag coefficient C_D of a car moving with speed v through air of density ρ is given by

$$C_D = \frac{F}{\frac{1}{2}\rho v^2 A}.$$

where F is the drag force exerted on the car and A is the maximum cross-sectional area of the car perpendicular to the direction of travel. Show that C_D is dimensionless (i.e. that it does not have a unit).

When a certain car is travelling at a speed of 20 m s^{-1} it experiences a drag force of 350 N. What drag force would be expected when the car is travelling at its top speed of 40 m s^{-1}? J87/II/2

***20** The unit J s^{-1} can be used as the unit of power instead of the watt. Give a unit for each of the following quantities using appropriate combinations of metre (m), second (s), ampere (A), joule (J), and volt (V) only.

Quantity
energy
pressure
electrical charge
electrical resistance [4]

J88/II/1

21 Bernoulli's equation, which applies to fluid flow, states that

$$p + h\rho g + \tfrac{1}{2}\rho v^2 = k$$

where p is a pressure, h a height, ρ a density, g an acceleration, v a velocity and k a constant. Show that the equation is dimensionally consistent and state an SI unit for k. [4]

N89/II/1

22 *(a)* How is work related to force and displacement? [1]

(b) Express the joule in terms of base units. [2]

(c) The theory of gas flow through small diameter tubes at low pressures is an important consideration of high vacuum technique. One equation which occurs in the theory is

$$Q = \frac{kr^3(p_1 - p_2)}{l}\sqrt{\frac{M}{RT}}.$$

where k is a number without units, r is the radius of the tube, p_1 and p_2 are the pressures at each end of the tube of length l, M is the molar mass of the gas (unit: kg mol^{-1}), R is the molar gas constant (unit: J K^{-1} mol^{-1}) and T is the temperature. Use the equation to find the base units of Q. [5]

* *(d)* In using the equation given in *(c)*, the value of r is $(1.67 \pm 0.03) \times 10^{-4}$ m. What percentage uncertainty does this introduce into the value of Q? [2] N93/II/1

23 *(a)* An A Level student suggests a number of equations, not all of which are correct. The equations are given in the table below. Place a tick or a cross in the last column to indicate whether a consideration of the units involved makes each equation possible (✓) or impossible (✗). [4]

surface area of a sphere = $\frac{4}{3}\pi r^3$	
speed of a wave = $\frac{\lambda}{T}$	
period of an oscillating pendulum = $2\pi\sqrt{\frac{g}{l}}$	
pressure of a gas = $\frac{1}{3}\rho<c^2>$	

r, l, λ are distances, c is a speed, g is an acceleration, T is a time and ρ is a density.

(b) Give an SI unit and an estimate of the magnitude of each of the following physical quantities. (Marks will be awarded for the correct order of magnitude of each estimate, not for its accuracy.) [7]

	magnitude	unit
the weight of an adult		
the power of a hair drier		
the energy required to bring to the boil a kettleful of water		
the resistance of a domestic filament lamp		
the wavelength of visible light		

J99/II/1

24 *(a)* The kilogram, the metre and the second are base units. Name two other base units. [2]

(b) Explain why the unit of energy is said to be a *derived* unit. [2]

(c) The density ρ and the pressure p of a gas are related by the expression

$$c = \sqrt{\frac{\gamma p}{\rho}},$$

where c and γ are constants.

(i) 1. Determine the base units of density ρ.

2. Show that the base units of pressure p are kg m^{-1} s^{-2}.

(ii) Given that the constant γ has no unit, determine the unit of c.

(iii) Using your answer to (ii), suggest what quantity may be represented by the symbol c. [6]

N2000/II/1

Long Questions

25 The critical flow speed v_c is related to the width a of the obstacle, the density ρ of the liquid, and its viscosity η by **one** of the equations:

(a) $v_c = A\eta a/\rho$, *(b)* $v_c = B\eta/a\rho$, *(c)* $v_c = C\rho a/\eta$.

A, B and C are dimensionless constants. Use the method of dimensions to identify the correct equation.

Discuss briefly whether, in general, the method of dimensional checking can positively confirm the correctness of an equation.

When a liquid (of density 1.0×10^3 kg m^{-3} and viscosity 1.0×10^{-4} Pa s) flows past an obstacle of width 15 mm, turbulence occurs for flow-speeds greater than 80 mm s^{-1}. What critical flow speed would be expected for a liquid of density 13.6×10^3 kg m^{-3} and viscosity 1.6×10^{-4} Pa s flowing past an object of similar shape and of width 5 mm?

N77/I/13 (part)

26 *(b)* (i) How do you check a formula for dimensional consistency? Why does this method of checking not give definite confirmation that an equation is correct?

(ii) Express the unit of force and of charge in terms of the SI base units kilogram, metre, second and ampere. Hence, by reference to Coulomb's law

$$F = \frac{1}{4\pi\epsilon_0}\frac{Q_1Q_2}{r^2}$$

express the unit of ϵ_0 the permittivity of a vacuum, in terms of these base units.

A unit of μ_0, the permeability of a vacuum, is kg m s^{-2} A^{-2}. Use the unit, and your unit of ϵ_0, to decide which one of the following relations between ϵ_0, μ_0 and c, the speed of light in a vacuum, is dimensionally consistent:

$$\epsilon_0\mu_0 = c^2;\ \epsilon_0\mu_0 = c;\ \epsilon_0\mu_0 = c^{-1};\ \epsilon_0\mu_0 = c^{-2}.$$

J82/I/13 (part)

27 Explain the meaning of the terms *(a) base unit,*

How do you check a formula for dimensional consistency? State *two* ways in which an equation that is dimensionally consistent may nevertheless be physically incorrect.

*The current density J in a thermionic diode with parallel, plane electrodes separated by a distance d depends on the potential difference V between anode and cathode. Use the dimensions or base units of the relevant quantities to find whether the equations:

$J = A\mu_0^{-1}(e/m_e)^{-1/2}\, V^{1/2}\, d^{-2}$ .... (i)

$J = B\epsilon_0(e/m_e)^{1/2}\, V^{3/2}\, d^{-2}$ .... (ii)

are dimensionally consistent. (In these equations, μ_0 and ϵ_0 are the permeability and permittivity of vacuum, and e/m_e is the specific charge of the electron; A and B are dimensionless constants.)

N84/I/13 (part)

***28** An equation for the speed v of longitudinal waves in a thin rod of an elastic solid of Young modulus E and density ρ is $v = (E/\rho)^{1/2}$. Using the base units or dimensions of the quantities involved, show that this equation in dimensionally homogeneous. [3]

N87/II/13 (part)

Avogadro Constant

29 A sample of carbon-12 has a mass of 3.0 g.

Which expression gives the number of atoms in the sample? (N_A is the symbol for the Avogadro constant.)

A 0.0030 N_A **B** 0.25 N_A **C** 3.0 N_A **D** 4.0 N_A

N97/I/1

30 Argon and neon are monatomic gases. One mole of argon has mass 40 g and one mole of neon has mass 20 g.

What is the ratio $\frac{\text{number of atoms in 1 mole of argon}}{\text{number of atoms in 1 mole of neon}}$?

A always 1
B always 2
C 1, only if both gases are at the same temperature and pressure
D 2, only if both gases are at the same temperature and pressure

N2000/I/1

31 *(a)* The value of the Avogadro constant is 6.02×10^{23} per mole.

(i) Define the mole.

(ii) Calculate the mass of an atom of ^{12}C, using the above value of the Avogadro constant.

(c) A solid iron cube of side 20 mm has a mass of 6.3×10^{-2} kg. One mole of iron atoms has a mass of 5.6×10^{-2} kg.

(i) How many iron atoms are there in the cube?

(ii) Hence find the maximum volume that an iron atom could occupy in the solid state.

(iii) Use your answer to *(c)* (ii) above to estimate the diameter of an iron atom.

N82/I/17 (part)

Scalars & Vectors

32 Forces of 5N, 4N and 3N are in equilibrium. Assuming that sin 37° = 0.6, the angle between the 5N force and the 3N force is

A 37° **B** 53° **C** 90° **D** 127° **E** 143°

J76/II/5

33 A horizontal force F is applied to a body of mass m on a smooth plane inclined at an angle θ to the horizontal, as shown in Fig. 1.

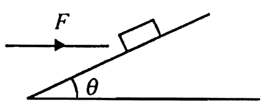


Fig. 1

The magnitude of the resultant force acting on the body is

A $F\cos\theta - mg\sin\theta$
B $F\sin\theta + mg\cos\theta$
C $F\sin\theta - mg\cos\theta$
D $F\cos\theta + mg\sin\theta$
E $F + mg\tan\theta$

J77/II/4

34 Three men, Smith, Brown and Jones, are attempting to push a large object in the direction 0x, Smith exerts a force of 200 N at a direction 30° to 0x and Brown a force of 400 N at 60° to 0x, as shown in the diagram below (Fig. 2).

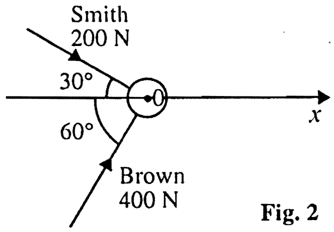
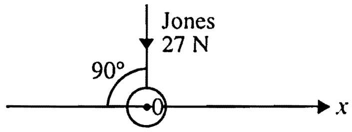
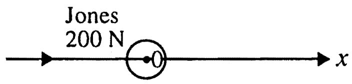
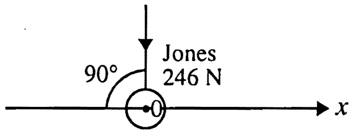


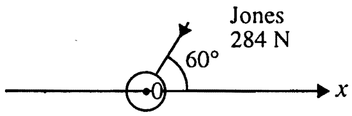
Fig. 2

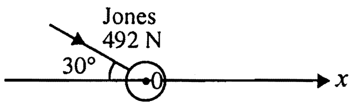
Which one of the following sketches correctly represents the magnitude and direction of the *smallest* force that Jones should exert such that the resultant of all three forces acts along 0x?

A


B


C


D


E


N80/II/7

35 A particle has an initial velocity of 15 m s^{-1} in the 0x direction, as shown in Fig. 3. At a later time its velocity is 15 m s^{-1} at an angle of 60° to 0x (Fig. 4). (Directions are indicated by measuring angles *anticlockwise* from the direction 0x.)

Fig. 3

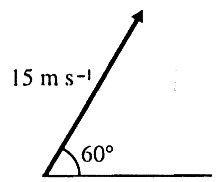


Fig. 4

The change of velocity that has taken place in this interval is

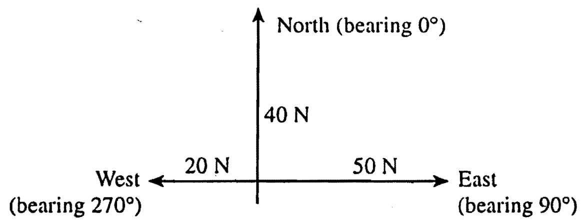
A zero
B 26 m s^{-1} at an angle of 30° to 0x.
C 15 m s^{-1} at an angle of 120° to 0x.
D 26 m s^{-1} at an angle of 210° to 0x.
E 15 m s^{-1} at an angle of 300° to 0x.

N85/I/1

36 Forces of 4N and 6N act at a point. Which one of the following could *not* be the magnitude of their resultant?

A 1 N	**D** 8 N		
B 4 N	**E** 10 N		
C 6 N			J86/I/1

37 Three coplanar forces, of magnitude 20 N, 40 N and 50 N, act on a body at P in the directions shown in the diagram below.



Which one of the following is the approximate bearing of the additional force required to maintain equilibrium?

A 37°	**D** 217°	
B 127°	**E** 233°	
C 143°		N86/I/1

38 Which pair includes a **vector** quantity and a **scalar** quantity?

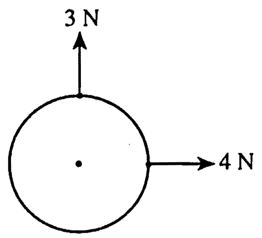
A displacement; acceleration
B force; kinetic energy
C power; speed
D work; potential energy N87/I/3; J94/I/1; J2000/I/1

39 Which list contains only scalar quantities?

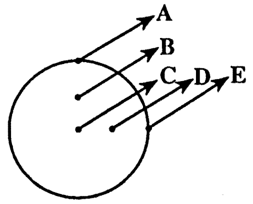
A mass, acceleration, temperature, kinetic energy
B mass, volume, electric potential, kinetic energy
C acceleration, temperature, volume, electric charge
D moment, electric field, density, magnetic flux
E kinetic energy, velocity, length, electric potential

N90/I/1

40 Two forces act on a circular disc as shown in the diagram.



Which arrow best shows the line of action of the resultant force?



N90/I/2

41 Which line in the table correctly identifies force, kinetic energy and momentum as scalar or vector quantities?

	force	*kinetic energy*	*momentum*
A	scalar	scalar	scalar
B	scalar	vector	vector
C	vector	scalar	scalar
D	vector	scalar	vector
E	vector	vector	vector

N92/I/1

42 'Velocity is a vector quantity, and the kinetic energy of a body is equal to half its mass times the square of its velocity, so kinetic energy must also be a vector.' Comment on the correctness of this argument. N77/I/1

43 A trolley of mass 0.80 kg runs freely, without accelerating, down an inclined plane when the plane makes an angle of 5.0° with the horizontal. Find the force parallel to the plane resisting the motion. [3]

N87/I/1

44 *(a)* What is meant by a *vector quantity*? [2]

(b) A ball is thrown into the air and, at one instant, it is moving upwards with a speed of 5.0 m s^{-1} at an angle of 60° to the vertical.

(i) Using a scale such that 1.0 cm represents a speed of 1.0 m s^{-1}, draw a line, starting at 0 on Fig. 5, to represent the velocity of the ball at that instant.

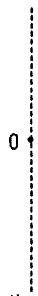


Fig. 5

(ii) On Fig. 5, construct lines to represent the vertical and the horizontal components of the velocity of the ball. Hence, from your drawing, determine

1. the vertical component of the velocity,
2. the horizontal component of the velocity. [5]

J95/II/1 (part)

45 The string of a particular bow is pulled back so that, just before the arrow is fired, the archer exerts a force of 260 N on the string, as shown in Fig. 6.

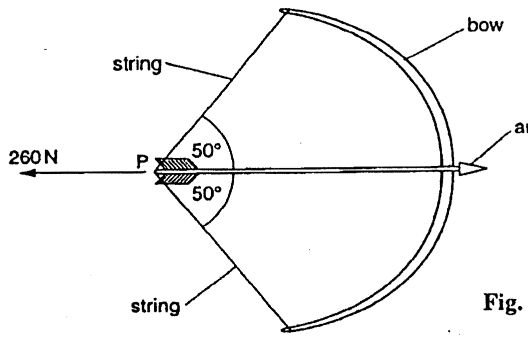


Fig. 6

The line of action of the 260 N force makes an angle of 50° with each section of the string.

The tension in the string is T.

(a) (i) On Fig. 6, indicate the directions of the tension in the two sections of the string at point P.

(ii) By calculation or scale drawing, determine the magnitude of the tension T in the string.

T = ... N[3]

N2000/II/2 (part)

Long Questions

46 Show by means of a labelled sketch how two vector quantities, acting at right angles, are added.

N80/I/13 (part)

47 A and B are two vectors acting at right angles. Draw labelled diagrams to show the vector addition (**A** + **B**) and the vector subtraction (**A** – **B**). State the magnitudes of the resultants and their directions with respect to vector **A**.

J83/I/13 (part)

48 *(a)* Some physical quantities are often paired together, one of the pair being a vector and the other a scalar. Identify the vector quantity in each of the following pairs.

(i) velocity and speed

(ii) weight and mass

(iii) energy and momentum

(iv) gravitational field strength and gravitational potential [4]

(b) Two vectors **A** and **B** are at right angles to each other. Draw a vector diagram to show how the sum of the vectors could be found. [2]

(c) A car changes its velocity from 30 m s^{-1} due East to 25 m s^{-1} due South.

(i) Draw a vector diagram to show the initial and final velocities and the change in velocity.

(ii) Calculate the change in speed.

(iii) Calculate the change in velocity. [6]

J89/II/8 (part)

49 *(a)* Distinguish between the *distance moved* by an object and its *displacement* from a fixed point. [2]

N95/III/2 (part)