WORKSHEET
Errors & Uncertainties
AS Level Physics 9702

9702/MJ/23/22/Q1

1 **(a)** **(i)** Define pressure.

....

.... [1]

(ii) Use the answer to **(a)(i)** to show that the SI base units of pressure are $kg\,m^{-1}\,s^{-2}$.

[1]

(b) A horizontal pipe has length L and a circular cross-section of radius R. A liquid of density ρ flows through the pipe. The mass m of liquid flowing through the pipe in time t is given by

$$m = \frac{\pi(p_2 - p_1)R^4\rho t}{8kL}$$

where p_1 and p_2 are the pressures at the ends of the pipe and k is a constant.

Determine the SI base units of k.

SI base units .... [3]

(c) An experiment is performed to determine the value of k by measuring the values of the other quantities in the equation in **(b)**.

The values of L and R each have a percentage uncertainty of 2%.

State and explain, quantitatively, which of these two quantities contributes more to the percentage uncertainty in the calculated value of k.

....

....

.... [1]

[Total: 6]

2 **(a)** **(i)** Define power.

....

.... [1]

(ii) Use the definition of power to show that the SI base units of power are $kg\,m^2\,s^{-3}$.

[1]

(b) The intensity I of a sound wave moving through a gas is given by

$$I = f^2A^2vk$$

where f is the frequency of the wave,
A is the amplitude of the wave,
v is the speed of the wave
and k is a constant that depends on the gas.

Determine the SI base units of k.

SI base units .... [3]

[Total: 5]

3 **(a)** Underline **all** the SI base units in the following list.

ampere coulomb current kelvin newton [1]

(b) A toy car moves in a horizontal straight line. The displacement *s* of the car is given by the equation

$$s = \frac{v^2}{2a}$$

where *a* is the acceleration of the car and *v* is its final velocity.

State **two** conditions that apply to the motion of the car in order for the above equation to be valid.

1 ....

2 ....
[2]

(c) An experiment is performed to determine the acceleration of the car in **(b)**. The following measurements are obtained:

$s = 3.89\,\text{m} \pm 0.5\%$
$v = 2.75\,\text{m}\,\text{s}^{-1} \pm 0.8\%$.

(i) Calculate the acceleration *a* of the car.

a = ... $\text{m}\,\text{s}^{-2}$ [1]

(ii) Determine the percentage uncertainty, to two significant figures, in *a*.

percentage uncertainty = ... % [2]

(iii) Use your answers in **(c)(i)** and **(c)(ii)** to determine the absolute uncertainty in the calculated value of *a*.

absolute uncertainty = ... $\text{m}\,\text{s}^{-2}$ [1]

[Total: 7]

4 **(a)** State what is meant by work done. 9702/ON/22/22/Q1

....

.... [1]

(b) Use the answer to **(a)** to determine the SI base units of power.

SI base units .... [2]

(c) The maximum useful output power P of a car travelling on a horizontal road is given by

$$P = v^3 b$$

where v is the maximum speed of the car and b is a constant.

For the car,

$P = 84\,\text{kW} \pm 5\%$
and $b = 0.56 \pm 7\%$ in SI units.

(i) Calculate the value of v.

v = ... m s^{-1} [2]

(ii) Determine the absolute uncertainty in the value of v.

absolute uncertainty = ... m s^{-1} [2]

[Total: 7]

9702/ON/22/21/Q1

5 **(a)** The boxes in Fig. 1.1 contain terms on the left-hand side and examples of these terms on the right-hand side.

Draw a line between each term on the left and the correct example on the right.

base quantity	coulomb
base unit	electric current
derived quantity	force
derived unit	kilogram

Fig. 1.1

[2]

(b) A set of experimental measurements is described as precise and not accurate.

State what is meant by:

(i) precise

....

.... [1]

(ii) not accurate.

....

.... [1]

(c) An object of mass *m* travels with speed *v* in a circle of radius *r*. The force *F* acting on the object is given by

$$F = \frac{mv^2}{r}.$$

The percentage uncertainties of three of the quantities are given in Table 1.1.

Table 1.1

quantity	percentage uncertainty
F	±3%
m	±4%
r	±5%

The value of *v* is determined from *F*, *m* and *r*.

(i) Calculate the percentage uncertainty in *v*.

percentage uncertainty = ... % [2]

(ii) The value of *v* is 15.0 $m s^{-1}$.

Calculate the absolute uncertainty in *v*.

absolute uncertainty = ... $m s^{-1}$ [1]

[Total: 7]

6 **(a)** In the following list, underline all units that are SI base units.

ampere degree Celsius kilogram newton [1]

(b) Fig. 1.1 shows a horizontal beam clamped at one end with a block attached to the other end.

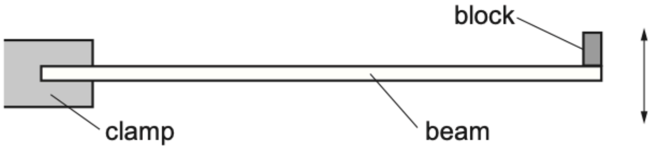


Fig. 1.1

The block is made to oscillate vertically.

The Young modulus E of the material of the beam is given by

$$E = \frac{kM}{T^2}$$

where M is the mass of the block,
T is the period of the oscillations
and k is a constant.

A student determines the values and percentage uncertainties of k, M and T.
Table 1.1 lists the percentage uncertainties.

Table 1.1

quantity	percentage uncertainty
k	±2.1%
M	±0.6%
T	±1.5%

The student uses the values of k, M and T to calculate the value of E as 8.245×10^9 Pa.

(i) Calculate the percentage uncertainty in the value of E.

percentage uncertainty = ... % [2]

7 **(a)** A unit may be stated with a prefix that represents a power-of-ten multiple or submultiple.

Complete Table 1.1 to show the name and symbol of each prefix and the corresponding power-of-ten multiple or submultiple.

Table 1.1

prefix	power-of-ten multiple or submultiple
kilo (k)	10^3
tera (T)	
( )	10^{-12}

[2]

(b) In the following list, underline all the units that are SI base units.

ampere   coulomb   metre   newton   [1]

(c) The potential difference V between the two ends of a uniform metal wire is given by

$$V = \frac{4\rho L I}{\pi d^2}$$

where d is the diameter of the wire,
I is the current in the wire,
L is the length of the wire,
and ρ is the resistivity of the metal.

For a particular wire, the percentage uncertainties in the values of some of the above quantities are listed in Table 1.2.

Table 1.2

quantity	percentage uncertainty
d	±3.0%
I	±2.0%
L	±2.5%
V	±3.5%

The quantities listed in Table 1.2 have values that are used to calculate ρ as $4.1 \times 10^{-7}\,\Omega\,m$.

For this value of ρ, calculate:

(i) the percentage uncertainty

percentage uncertainty = ...% [2]

(ii) the absolute uncertainty.

absolute uncertainty = ... $\Omega\,m$ [1]

[Total: 6]

8 **(a)** Define *density*.

....

.... [1]

(b) A smooth pebble, made from uniform rock, has the shape of an elongated sphere as shown in Fig. 1.1.

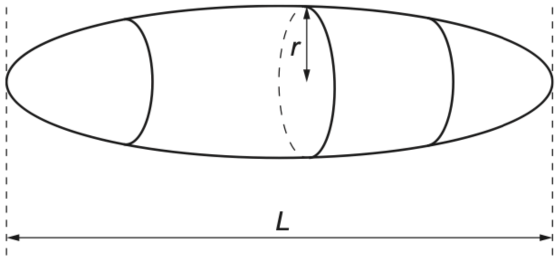


Fig. 1.1

The length of the pebble is L. The cross-section of the pebble, in the plane perpendicular to L, is circular with a maximum radius r.

A student investigating the density of the rock makes measurements to determine the values of L, r and the mass M of the pebble as follows:

$$L = (0.1242 \pm 0.0001)\,\text{m}$$
$$r = (0.0420 \pm 0.0004)\,\text{m}$$
$$M = (1.072 \pm 0.001)\,\text{kg}.$$

(i) State the name of a measuring instrument suitable for making this measurement of L.

.... [1]

(ii) Determine the percentage uncertainty in the measurement of r.

percentage uncertainty = ... % [1]

(c) The density ρ of the rock from which the pebble in **(b)** is composed is given by

$$\rho = \frac{Mr^n}{kL}$$

where n is an integer and k is a constant, with no units, that is equal to 2.094.

(i) Use SI base units to show that n is equal to –2.

[2]

(ii) Calculate the percentage uncertainty in ρ.

percentage uncertainty = ... % [3]

(iii) Determine ρ with its absolute uncertainty. Give your values to the appropriate number of significant figures.

ρ = (..................................... ± ....) kg m^{-3} [3]

[Total: 11]

9 **(a)** Define *density*. 9702/21/M/J/21/Q1

....

.... [1]

(b) Fig. 1.1 shows a solid pyramid with a square base.

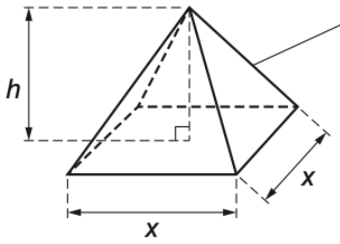


Fig. 1.1

The mass m of the pyramid is given by

$$m = \frac{1}{3}\rho h x^2$$

where ρ is the density of the material of the pyramid,
h is the height, and
x is the length of each side of the base.

Measurements are taken as shown in Table 1.1.

Table 1.1

quantity	measurement	percentage uncertainty
m	19.5 g	±2%
x	4.0 cm	±5%
h	4.8 cm	±4%

(i) Calculate the absolute uncertainty in length x.

absolute uncertainty = ... cm [1]

(ii) The density ρ is calculated from the measurements in Table 1.1.

Determine the percentage uncertainty in the calculated value of ρ.

percentage uncertainty = ... % [2]

(c) The square base of the pyramid in **(b)** rests on the horizontal surface of a bench.

Use data from Table 1.1 to calculate the average pressure of the pyramid on the surface of the bench. The uncertainty in your answer is not required.

pressure = ... Pa [3]

[Total: 7]

10 **(a)** Define *velocity*. **9702/21/M/J/19/Q1**

....

....[1]

(b) The speed v of a sound wave through a gas of pressure P and density ρ is given by the equation

$$v = \sqrt{\frac{kP}{\rho}}$$

where k is a constant that has no units.

An experiment is performed to determine the value of k. The data from the experiment are shown in Fig. 1.1.

quantity	value	uncertainty
v	$3.3 \times 10^2\,\mathrm{m\,s^{-1}}$	± 3%
P	$9.9 \times 10^4\,\mathrm{Pa}$	± 2%
ρ	$1.29\,\mathrm{kg\,m^{-3}}$	± 4%

Fig. 1.1

(i) Use data from Fig. 1.1 to calculate k.

k = ... [2]

(ii) Use your answer in **(b)(i)** and data from Fig. 1.1 to determine the value of k, with its absolute uncertainty, to an appropriate number of significant figures.

k = ... ± .... [3]

[Total: 6]

11 **(a)** The diameter d of a cylinder is measured as 0.0125 m ± 1.6%. 9702/22/M/J/19/Q1

Calculate the absolute uncertainty in this measurement.

absolute uncertainty = ... m [1]

(b) The cylinder in **(a)** stands on a horizontal surface. The pressure p exerted on the surface by the cylinder is given by

$$p = \frac{4W}{\pi d^2}.$$

The measured weight W of the cylinder is 0.38 N ± 2.8%.

(i) Calculate the pressure p.

p = ... $N\,m^{-2}$ [1]

(ii) Determine the absolute uncertainty in the value of p.

absolute uncertainty = ... $N\,m^{-2}$ [2]

[Total: 4]

9702/23/M/J/18/Q1

12 **(a)** An analogue voltmeter is used to take measurements of a constant potential difference across a resistor.

For these measurements, describe **one** example of

(i) a systematic error,

....

....[1]

(ii) a random error.

....

....[1]

(b) The potential difference across a resistor is measured as 5.0 V ± 0.1 V. The resistor is labelled as having a resistance of 125 Ω ± 3%.

(i) Calculate the power dissipated by the resistor.

power = ... W [2]

(ii) Calculate the percentage uncertainty in the calculated power.

percentage uncertainty = ... % [2]

(iii) Determine the value of the power, with its absolute uncertainty, to an appropriate number of significant figures.

power = ... ± .... W [2]

[Total: 8]

13 One end of a wire is connected to a fixed point. A load is attached to the other end so that the wire hangs vertically.

The diameter d of the wire and the load F are measured as

$d = 0.40 \pm 0.02\,\text{mm}$,
$F = 25.0 \pm 0.5\,\text{N}$.

(a) For the measurement of the diameter of the wire, state

(i) the name of a suitable measuring instrument,

....[1]

(ii) how random errors may be reduced when using the instrument in **(i)**.

....

....

....[2]

(b) The stress σ in the wire is calculated by using the expression

$$\sigma = \frac{4F}{\pi d^2}.$$

(i) Show that the value of σ is $1.99 \times 10^8\,\text{N}\,\text{m}^{-2}$.

[1]

(ii) Determine the percentage uncertainty in σ.

percentage uncertainty = ...% [2]

(iii) Use the information in **(b)(i)** and your answer in **(b)(ii)** to determine the value of σ, with its absolute uncertainty, to an appropriate number of significant figures.

σ = ... ± .... $N m^{-2}$ [2]

[Total: 8]

14 **(a)** Define *density*. **9702/21/O/N/16/Q1**

....

....[1]

(b) The mass *m* of a metal sphere is given by the expression

$$m = \frac{\pi d^3 \rho}{6}$$

where ρ is the density of the metal and *d* is the diameter of the sphere.

Data for the density and the mass are given in Fig. 1.1.

quantity	value	uncertainty
ρ	$8100\,kg\,m^{-3}$	± 5%
m	7.5 kg	± 4%

Fig. 1.1

(i) Calculate the diameter *d*.

d = ... m [1]

(ii) Use your answer in **(i)** and the data in Fig. 1.1 to determine the value of *d*, with its absolute uncertainty, to an appropriate number of significant figures.

d = ... ± .... m [3]

[Total: 5]

15 **(a)** Make estimates of **9702/21/M/J/16/Q1**

(i) the mass, in kg, of a wooden metre rule,

mass = ... kg [1]

(ii) the volume, in cm^3, of a cricket ball or a tennis ball.

volume = ... cm^3 [1]

(b) A metal wire of length L has a circular cross-section of diameter d, as shown in Fig. 1.1.

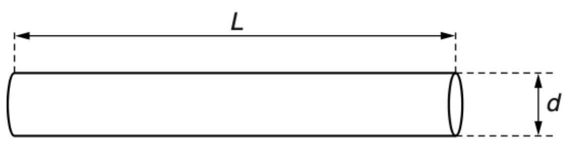


Fig. 1.1

The volume V of the wire is given by the expression

$$V = \frac{\pi d^2 L}{4}.$$

The diameter, length and mass M are measured to determine the density of the metal of the wire. The measured values are:

$d = 0.38 \pm 0.01$ mm,
$L = 25.0 \pm 0.1$ cm,
$M = 0.225 \pm 0.001$ g.

Calculate the density of the metal, with its absolute uncertainty. Give your answer to an appropriate number of significant figures.

density = ... ± .... kg m^{-3} [5]

[Total: 7]

9702/23/M/J/16/Q2

16 **(a)** Describe the effects, one in each case, of systematic errors and random errors when using a micrometer screw gauge to take readings for the diameter of a wire.

systematic errors: ....

....

random errors: ....

....
[2]

(b) Distinguish between precision and accuracy when measuring the diameter of a wire.

precision: ....

....

accuracy: ....

....
[2]

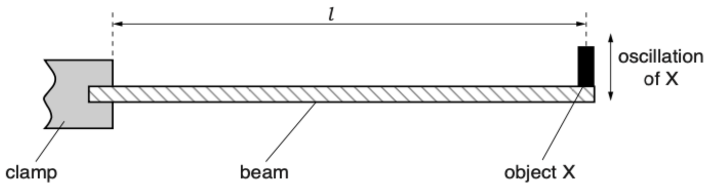
[Total: 4]

17 **(a)** State two SI base quantities other than mass, length and time. 9702/21/O/N/15/Q1

1. ....

2. ....
[2]

(b) A beam is clamped at one end and an object X is attached to the other end of the beam, as shown in Fig. 1.1.



The object X is made to oscillate vertically.

The time period T of the oscillations is given by

$$T = K\sqrt{\frac{Ml^3}{E}}$$

i Data in SI units for the oscillations of X are shown in Fig. 1.2.

quantity	value	uncertainty
T	0.45	± 2.0%
l	0.892	± 0.2%
M	0.2068	± 0.1%
K	1.48×10^5	± 1.5%

Fig. 1.2

Calculate E and its actual uncertainty.

E = ... ± .... $kg\,m^{-1}\,s^{-2}$ [4]

18 **(a)** Define *pressure*. **9702/21/O/N/14/Q2**

.... [1]

(b) A cylinder is placed on a horizontal surface, as shown in Fig. 2.1.

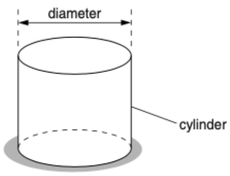


Fig. 2.1

The following measurements were made on the cylinder:

mass = 5.09 ± 0.01 kg
diameter = 9.4 ± 0.1 cm.

(i) Calculate the pressure produced by the cylinder on the surface.

pressure = ... Pa [3]

(ii) Calculate the actual uncertainty in the pressure.

actual uncertainty = ... Pa [3]

(iii) State the pressure, with its actual uncertainty.

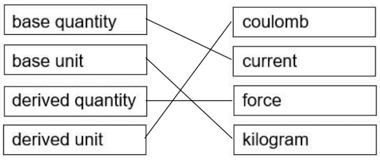
pressure = ... ± .... Pa [1]

1 on	Answer	Marks
1(a)(i)	force / area (normal to the force)	**B1**
1(a)(ii)	($p = F / A$ so units are) kg m s^{-2} / m^2 = kg m^{-1} s^{-2}	**A1**
1(b)	unit of R: m **and** unit of t: s **and** unit of L: m	**C1**
	unit of ρ: kg m^{-3} **or** $\rho = m / V$	**C1**
	base units of k: (kg m^{-1} s^{-2} × m^4 × kg m^{-3} × s) / (kg × m) = kg m^{-1} s^{-1}	**A1**
1(c)	R contributes 4 × 2% **or** 8% (and L contributes 2%) so R contributes more (to the percentage uncertainty in k)	**B1**

2 on	Answer	Marks
1(a)(i)	work done per unit time	**B1**
1(a)(ii)	($P = W / t$ gives) units: kg m^2 s^{-2} / s = kg m^2 s^{-3}	**B1**
1(b)	($I = P / A$ so) units of I: kg m^2 s^{-3} / m^2 or kg s^{-3}	**C1**
	units of f: s^{-1} **and** units of A: m **and** units of v: m s^{-1}	**C1**
	units of k: kg s^{-3} / [$(s^{-1})^2$ m^2 m s^{-1}] = kg m^{-3}	**A1**

3 on	Answer	Marks
1(a)	only ampere and kelvin underlined	**B1**
1(b)	initial speed / velocity is zero	**B1**
	(non-zero magnitude of) acceleration is constant / uniform (and in a straight line)	**B1**
1(c)(i)	$a = 2.75^2 / (2 \times 3.89)$ = 0.97 m s^{-2}	**A1**
1(c)(ii)	percentage uncertainty = (2 × 0.8) + 0.5	**C1**
	= 2.1%	**A1**
1(c)(iii)	absolute uncertainty = (2.1 / 100) × 0.97 = 0.02 m s^{-2}	**A1**

4 on	Answer	Marks
1(a)	force × displacement in the direction of the force	**B1**
1(b)	$P = Fs / t$ = (kg m s^{-2} × m) / s	**C1**
	= kg m^2 s^{-3}	**A1**
1(c)(i)	$84 \times 10^3 = v^3 \times 0.56$	**C1**
	v = 53 m s^{-1}	**A1**
1(c)(ii)	percentage uncertainty = (5% + 7%) / 3 (= 4%) **or** fractional uncertainty = (0.05 + 0.07) / 3 (= 0.04)	**C1**
	absolute uncertainty = 0.04 × 53 = (±) 2 m s^{-1}	**A1**

5 …on	Answer	Marks
1(a)	 any two joined correctly	C1
	all four joined correctly	A1
1(b)(i)	the measurements have a small range	B1
1(b)(ii)	(average of the) measurements not close to the true value	B1
1(c)(i)	percentage uncertainty = (3 + 5 + 4) / 2	C1
	= 6%	A1
1(c)(ii)	absolute uncertainty = (6 / 100) × 15.0 = 0.9 $m\,s^{-1}$	A1

6 …on	Answer	Marks
1(a)	10^{12}	B1
	pico (p)	B1
1(b)	ampere and metre both underlined (and no other units underlined)	B1
1(c)(i)	percentage uncertainty = 3.5 + (3.0 × 2) + 2.5 + 2.0	C1
	= 14%	A1
1(c)(ii)	absolute uncertainty = $4.1 \times 10^{-7} \times 14 / 100$ = $6 \times 10^{-8}\,\Omega\,m$	A1

7 …on	Answer	Marks
1(a)	mass / volume	B1
1(b)(i)	(vernier/digital) calipers	B1
1(b)(ii)	percentage uncertainty = (0.0004 / 0.0420) × 100 = 1%	A1
1(c)(i)	$kg\,m^{-3} = kg \times m^n / m$ **or** $kg\,m^{-3} = kg \times m^n \times m^{-1}$	M1
	$-3 = n - 1$ and (so) $n = -2$	A1
1(c)(ii)	$(\Delta\rho / \rho) = (\Delta M / M) + 2(\Delta r / r) + (\Delta L / L)$	C1
	percentage uncertainty = [(0.001 / 1.072) + 2 × (0.0004 / 0.0420) + (0.0001 / 0.1242)] (× 100)	C1
	= 0.09% + 2 × 0.95% + 0.08% = 2%	A1
1(c)(iii)	$\rho = (1.072 \times 0.0420^{-2}) / (2.094 \times 0.1242)$ = 2337 ($kg\,m^{-3}$)	C1
	$\Delta\rho = 0.021 \times 2337$ = 49 ($kg\,m^{-3}$)	C1
	$\rho = (2340 \pm 50)\,kg\,m^{-3}$	A1

8

stion	Answer
1(a)	mass / volume
1(b)(i)	absolute uncertainty $= 4.0 \times (5 / 100)$
	$= (\pm)\ 0.2$ cm
1(b)(ii)	percentage uncertainty $= 2 + 4 + (5 \times 2)$
	$= (\pm)\ 16\%$
1(c)	$p = F / A$ **or** $p = W / A$
	$p = (19.5 \times 10^{-3} \times 9.81) / (4.0 \times 10^{-2})^2$
	$= 120$ Pa

9	2(a)	(velocity =) change in displacement / time (taken)
	(b)(i)	$k = [1.29 \times (3.3 \times 10^2)^2] / 9.9 \times 10^4$
		$= 1.4$
	(b)(ii)	percentage uncertainty = $(3 \times 2) + 4 + 2$ (= 12%) **or** fractional uncertainty = $(0.03 \times 2) + 0.04 + 0.02$ (= 0.12)
		$\Delta k = 0.12 \times 1.42$ $= 0.17$ (*allow to 1 significant figure*)
		$k = 1.4 \pm 0.2$
10	3(a)	absolute uncertainty $= (1.6 / 100) \times 0.0125$ $= 2 \times 10^{-4}$ m
	(b)(i)	$p = (4 \times 0.38) / (\pi \times 0.0125^2)$ $= 3100$ N m^{-2}
	(b)(ii)	percentage uncertainty $= 2.8 + (2 \times 1.6)$ (= 6%) **or** fractional uncertainty $= 0.028 + (2 \times 0.016)$ (= 0.06)
		absolute uncertainty $= 0.06 \times 3100$ $= 190$ N m^{-2} (*allow to 1 significant figure*)
11	(a)(i)	zero error **or** wrongly calibrated scale
	(a)(ii)	reading scale from different angles **or** wrongly interpolating between scale readings/divisions
	(b)(i)	$P = V^2 / R$ **or** $P = VI$ <u>and</u> $V = IR$
		$P = 5.0^2 / 125$ **or** 5.0×0.04 **or** $(0.04)^2 \times 125$ $= 0.20$ W
	(b)(ii)	$\%V = 2\%$ **or** $\Delta V / V = 0.02$
		$\%P = (2 \times 2\%) + 3\%$ **or** $\%P = (2 \times 0.02 + 0.03) \times 100$ $= 7\%$
	(b)(iii)	absolute uncertainty in $P = (7 / 100) \times 0.20$ $= 0.014$
		power $= 0.20 \pm 0.01$ W **or** $(2.0 \pm 0.1) \times 10^{1}$ W

12	(a)(i)	micrometer (screw gauge)/digital calipers
	(a)(ii)	take several readings (and average)
		along the wire **or** around the circumference
	(b)(i)	$\sigma = 4 \times 25 / [\pi \times (0.40 \times 10^{-3})^2] = 1.99 \times 10^8\ \text{N m}^{-2}$ **or** $\sigma = 25 / [\pi \times (0.20 \times 10^{-3})^2] = 1.99 \times 10^8\ \text{N m}^{-2}$
	(b)(ii)	$\%F = 2\%$ **and** $\%d = 5\%$ **or** $\Delta F / F = \frac{0.5}{25}$ **and** $\Delta d / d = \frac{0.02}{0.4}$
		$\%\sigma = 2\% + (2 \times 5\%)$ **or** $\%\sigma = [0.02 + (2 \times 0.05)] \times 100$ $\%\sigma = 12\%$
	(b)(iii)	absolute uncertainty $= (12/100) \times 1.99 \times 10^8$ $= 2.4 \times 10^7$
		$\sigma = 2.0 \times 10^8 \pm 0.2 \times 10^8\ \text{N m}^{\ 2}$ **or** $2.0 \pm 0.2 \times 10^8\ \text{N m}^{\ 2}$

13 **(a)** (density =) mass / volume

(b) **(i)** $d = [(6 \times 7.5)/(\pi \times 8100)]^{1/3}$

$= 0.12(1)\ \text{m}$

(ii) percentage uncertainty = (4 + 5) / 3 (= 3%)

or

fractional uncertainty = (0.04 + 0.05) / 3 (= 0.03)

absolute uncertainty (= 0.03 × 0.121) = 0.0036

$d = 0.121 \pm 0.004\ \text{m}$

14 **(a)** **(i)** $(50 \text{ to } 200) \times 10^{-3}\ \text{kg}$ or (0.05 to 0.2) kg

(ii) $(50 \text{ to } 300)\ \text{cm}^3$

(b) density = mass / volume or $\rho = M / V$

$V = [\pi(0.38 \times 10^{-3})^2 \times 25.0 \times 10^{-2}]/4\ (= 2.835 \times 10^{-8}\ \text{m}^3)$

$\rho = (0.225 \times 10^{-3})/2.835 \times 10^{-8}$
$= 7940\ (\text{kg m}^{-3})$

$\Delta\rho/\rho = 2(0.01/0.38) + (0.1/25.0) + (0.001/0.225)\ [= 0.061]$

or

$\%\rho = 5.3\% + 0.40\% + 0.44\%\ (= 6.1\%)$

$\Delta\rho = 0.061 \times 7940 = 480\ (\text{kg m}^{-3})$

density $= (7.9 \pm 0.5) \times 10^3\ \text{kg m}^{-3}$ or $(7900 \pm 500)\ \text{kg m}^{-3}$

15 **(a)** systematic: the reading is larger or smaller than (or varying from) the true reading by a constant amount

random: scatter in readings about the true reading

(b) precision: the size of the smallest division (on the measuring instrument)
or
0.01 mm for the micrometer

accuracy: how close (diameter) value is to the true (diameter) value

16 **(a)** temperature
current
(allow amount of substance, luminous intensity)

b (i) % uncertainty in E = 4% (for T^2) + 0.6% (for l^3) + 0.1% (for M) + 3% (for K^2)
= 7.7%

$E = [(1.48 \times 10^5)^2 \times 0.2068 \times (0.892)^3] / (0.45)^2$
$= 1.588 \times 10^{10}$

7.7% of $E = 1.22 \times 10^9$

$E = (1.6 \pm 0.1) \times 10^{10}\,\text{kg}\,\text{m}^{-1}\,\text{s}^{-2}$

17 **(a)** pressure = force / area (normal to the force) [clear ratio essential]

(b) **(i)** $P = mg / A = (5.09 \times 9.81) / A$

$A = (\pi d^2 / 4) = \pi \times (9.4 \times 10^{-2})^2 / 4$ (= 0.00694 m^2)

$P = 49.93 / 0.00694$
= 7200 (7195) Pa (minimum of 2 s.f. required)

(ii) $\Delta P / P = \Delta m / m + 2\Delta d / d$

= 0.01 / 5.09 + (2 × 0.1) / 9.4 (= 0.0020 + 0.021 or 2.3%)

ΔP = 170 (165 to 167) Pa

(iii) P = 7200 ± 200 Pa