Mass/g ±0.1 g	Length 1/cm ±0.05 cm	Length 2/cm ±0.05 cm	Length 3/cm ±0.05 cm	Length 4/cm ±0.05 cm
124.1	2.40	2.30	2.50	2.40
235.2	3.00	3.10	2.90	3.00
344.0	3.40	3.30	3.40	3.50
463.2	3.70	3.80	3.60	3.70
571.2	4.00	4.10	3.90	4.00
660.0	4.20	4.30	4.10	4.20

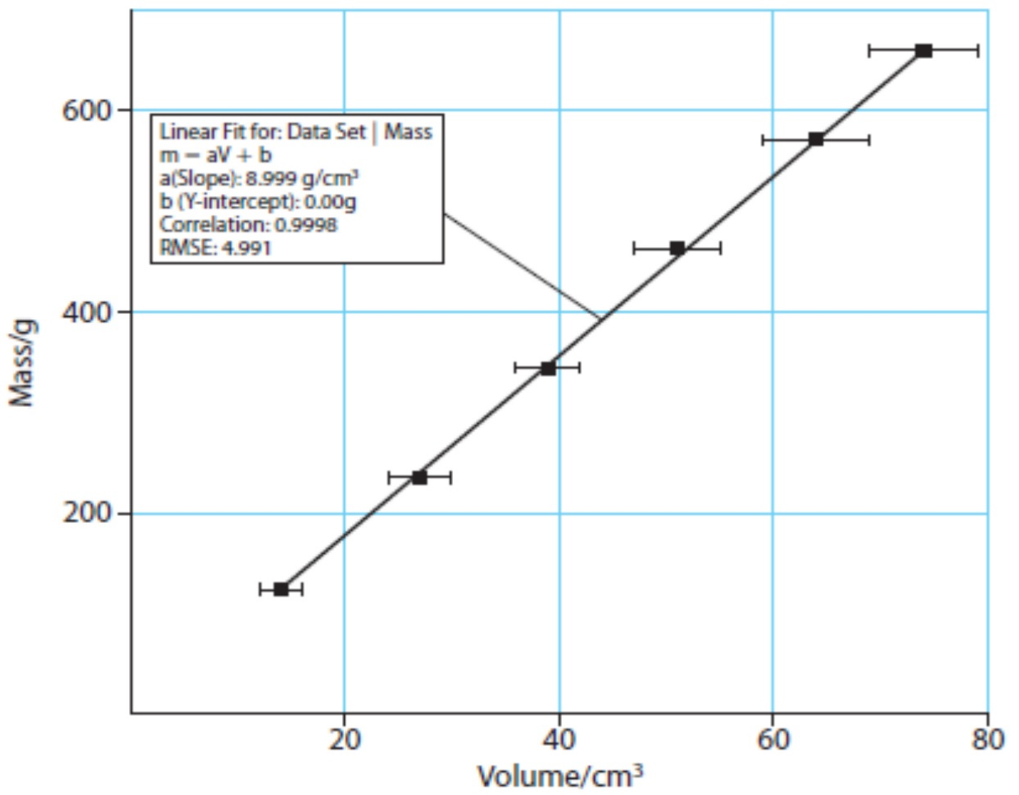
Note: The uncertainty in each length measurement is 0.05 cm. However the actual uncertainty is greater as the spread of values demonstrates.

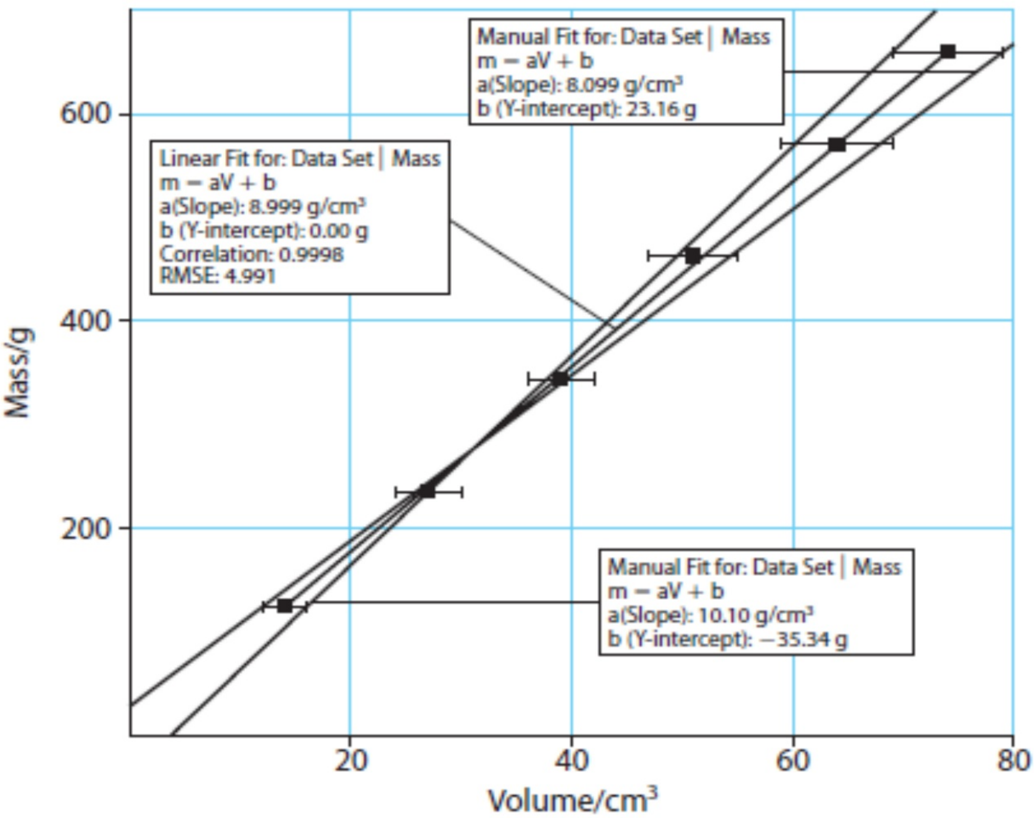
this.

This is calculated using the formula $((\text{max length})^3 - (\text{min length})^3)/2$

This is found by calculating (max length − (min length)/2

Mass/g ±0.1 g	Mean length/cm	Uncertainty in length/±cm	Volume/cm^3	Uncertainty in volume/±cm^3
124.1	2.4	0.1	14	2
235.2	3.0	0.1	27	3
344.0	3.4	0.1	39	3
463.2	3.7	0.1	51	4
571.2	4.0	0.1	64	5
660.0	4.2	0.1	74	5


Linear Fit for: Data Set | Mass
m = aV + b
a(Slope): 8.999 g/cm³
b (Y-intercept): 0.00g
Correlation: 0.9998
RMSE: 4.991
600
400
200
Mass/g
20
40
60
80
Volume/cm³


Manual Fit for: Data Set | Mass
m = aV + b
a(Slope): 8.099 g/cm³
b (Y-intercept): 23.16 g
Linear Fit for: Data Set | Mass
m = aV + b
a(Slope): 8.999 g/cm³
b (Y-intercept): 0.00 g
Correlation: 0.9998
RMSE: 4.991
Manual Fit for: Data Set | Mass
m = aV + b
a(Slope): 10.10 g/cm³
b (Y-intercept): −35.34 g
600
400
200
Mass/g
20
40
60
80
Volume/cm³

The maximum gradient is 10.1 and the minimum is 8.1 so the uncertainty is

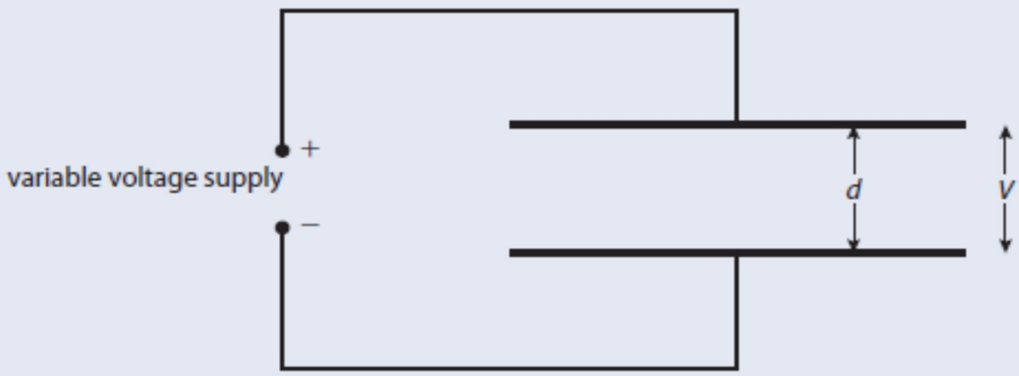
$$\frac{(10.1 - 8.1)}{2} = 1\,\mathrm{g\,cm^{-3}}$$

So our final result is that the density of the metal in SI units is $9000 \pm 1000\,\mathrm{kg\,m^{-3}}$.

Note the number of significant figures is reduced so that it is consistent with the uncertainty.

If we look up the density of metals we find that the density of copper is $8920\,\mathrm{kg\,m^{-3}}$. This is only $80\,\mathrm{kg\,m^{-3}}$ less than our value. We can therefore conclude that within the uncertainties of our experiment the cubes could be made of copper.

This question is about measuring the permittivity of free space ϵ_0.
The diagram below shows two parallel conducting plates connected to a variable voltage supply. The plates are of equal areas and are a distance *d* apart.



The charge Q on one of the plates is measured for different values of the potential difference V applied between the plates. The values obtained are shown in the table below. The uncertainty in the value of V is not significant but the uncertainty in Q is ±10%.

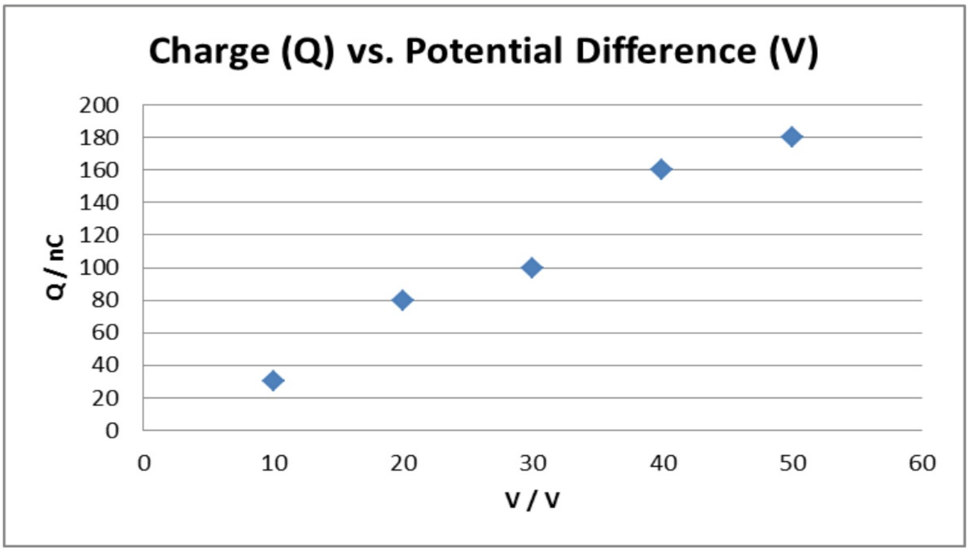
potential difference — Volts — charge — nC = nano-Coulomb

variable/units

V / V	Q / nC ± 10%
10.0	30
20.0	80
30.0	100
40.0	160
50.0	180

V / V (x)	Q / nC ± 10% (y)
10.0	30
20.0	80
30.0	100
40.0	160
50.0	180

(a) Plot the data points opposite on a graph of V (x-axis) against Q (y-axis). (4)



V / V	Q / nC ± 10%
10.0	30
20.0	80
30.0	100
40.0	160
50.0	180

(b) By calculating the relevant uncertainty in Q, add error bars to the data points (10.0, 30) and (50.0, 180). (3)

$\% \text{ uncert} = \frac{\Delta a}{a} * 100$

$\therefore \Delta a = \frac{\% \text{ uncert.}}{100} * a$

(10.0, 30)

$30 \pm 10\%$

$\text{abs. uncert} = \frac{10\%}{100} * 30$

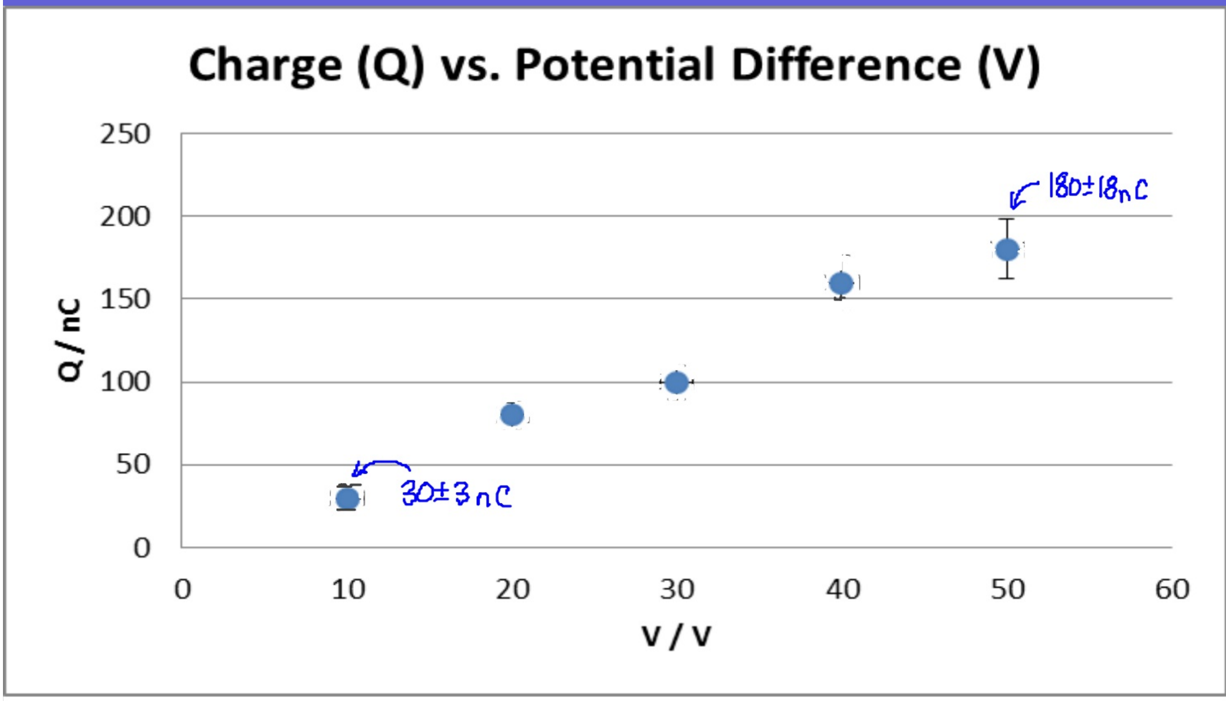
$= \pm 3 \text{ nC}$

(50.0, 180)

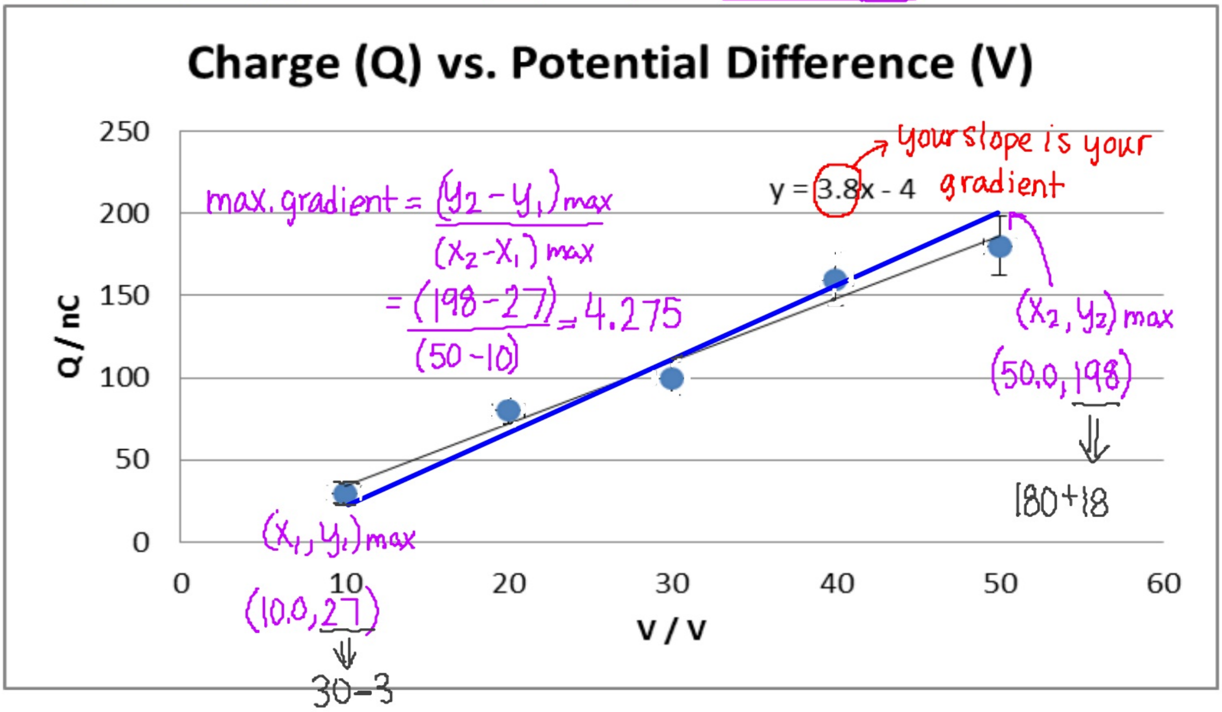
$180 \pm 10\%$

$\text{abs. uncert} = \frac{10\%}{100} * 180$

$= \pm 18 \text{ nC}$



(c) On your graph, draw the line that best fits the data points and has the maximum permissible gradient. Determine the gradient of the line that you have drawn. (3)



(d) The gradient of the graph is a property of the two plates and is known as *capacitance*.
Deduce the units of capacitance. (1)

(capacitance)
gradient ⇒ slope ⇒ $\frac{\text{rise}}{\text{run}}$ ⇒ $\frac{\text{potential difference}}{\text{charge}}$ ⇒ $\frac{V}{nC}$

∴ the units of capacitance are $\frac{V}{nC}$ = V C^{-1}

The relationship between Q and V for this arrangement is given by the expression

$$Q = \frac{\epsilon_0 A}{d} V$$

where A is the area of one of the plates.

In this particular experiment $A = 0.20 \pm 0.05\ \text{m}^2$ and $d = 0.50 \pm 0.01$ mm.

(e) Use your answer to **(c)** to determine the maximum value of ϵ_0 that this experiment yields. (4)

$$Q = \frac{\varepsilon_0 A}{d} V$$

$$\therefore \varepsilon_0 = \underbrace{\frac{Q}{V}}_{= \text{gradient (capacitance)}} \frac{d}{A}$$

$$\varepsilon_0 = \left(4.275 \frac{V}{nC}\right)\left(\frac{.50 \pm 0.01\,\text{mm}}{0.20 \pm 0.05\,\text{m}^2}\right)$$

max = .51 mm

max = .15 m^2

$$\frac{d}{A} = \frac{.51\,\cancel{\text{mm}}}{.15\,\text{m}^2} \left| \frac{1\,\cancel{\text{m}}}{1000\,\cancel{\text{mm}}} \right. = .0034\ \text{m}^{-1}$$

$$\varepsilon_{0\,(max)} = \left(4.275 \frac{V}{nC}\right)\left(.0034\ \text{m}^{-1}\right) \approx 0.014535 \frac{nC}{V\,m}$$

$= 1.4535 \times 10^{-11}$

$= 1.5 \times 10^{-11}\ \text{C V}^{-1}\text{m}^{-1}$