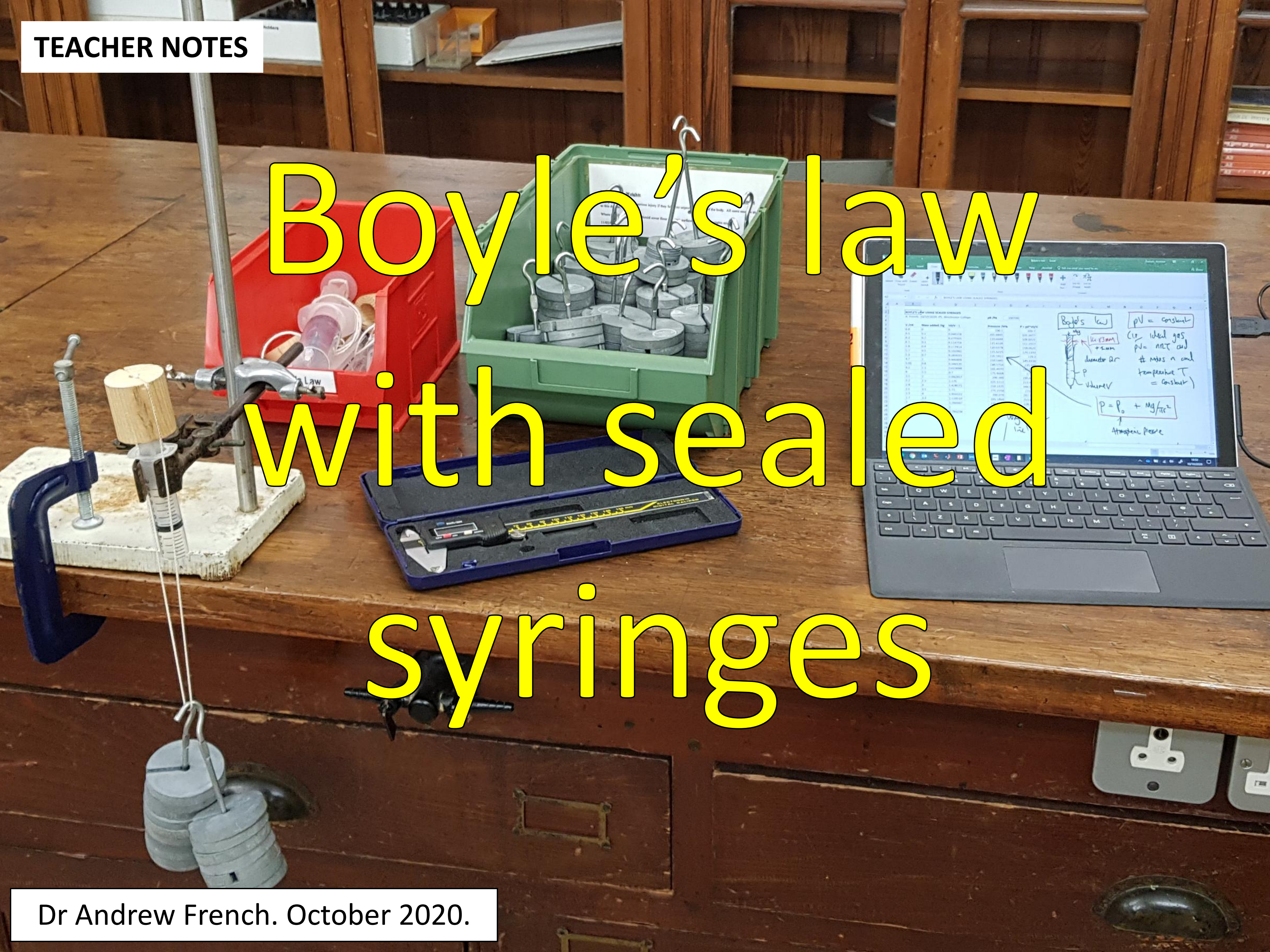
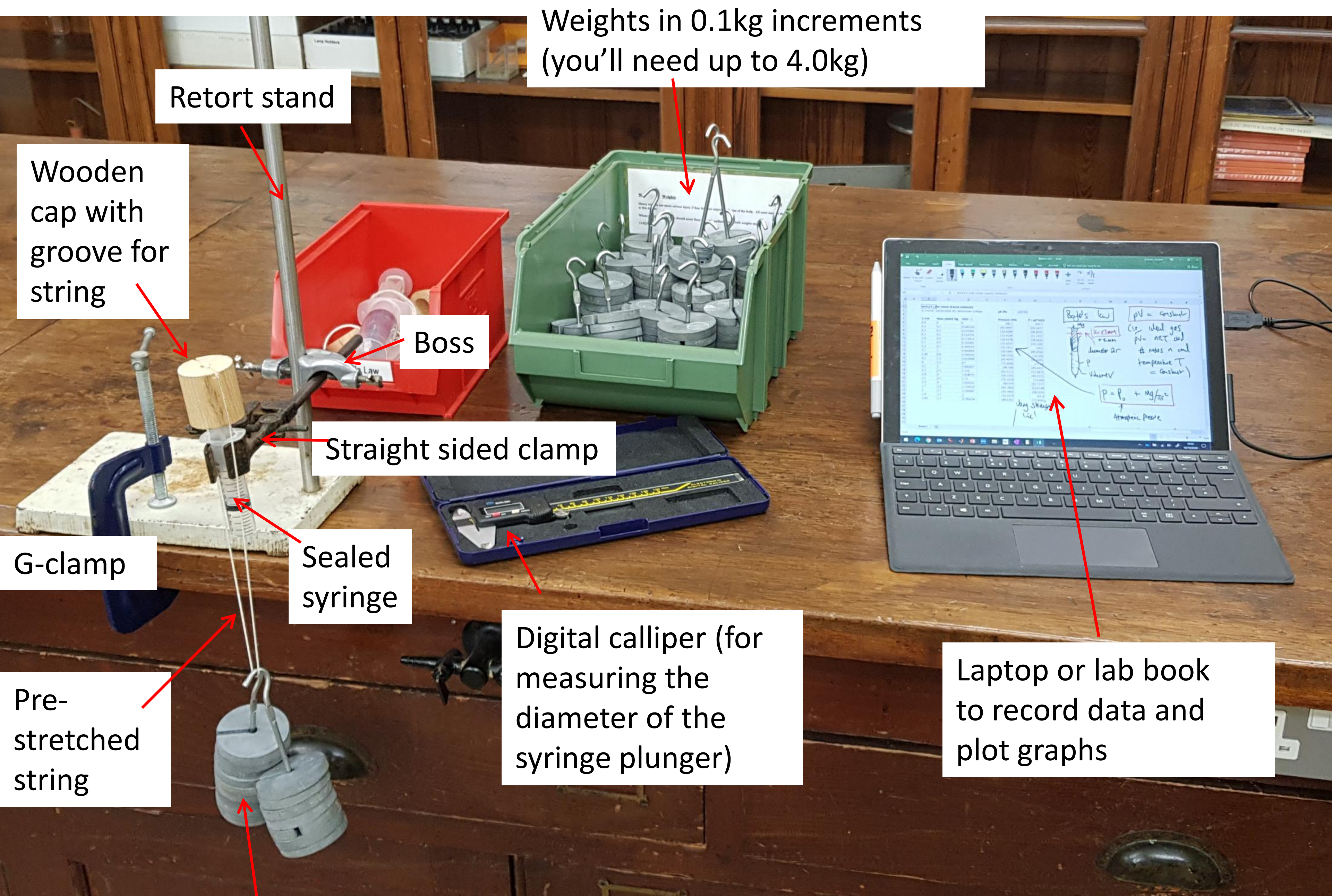
TEACHER NOTES

Boyle’s law with sealed syringes



Dr Andrew French. October 2020.



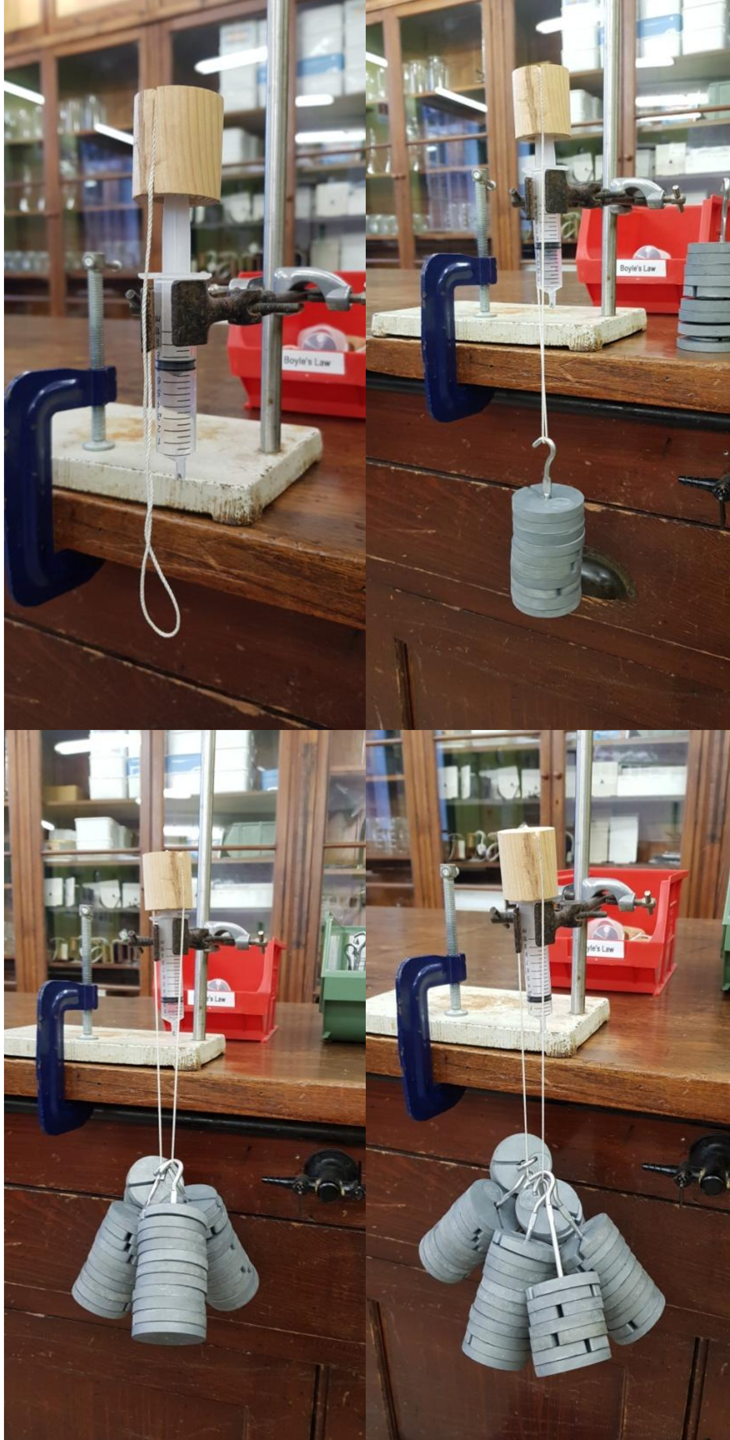
Equipment setup

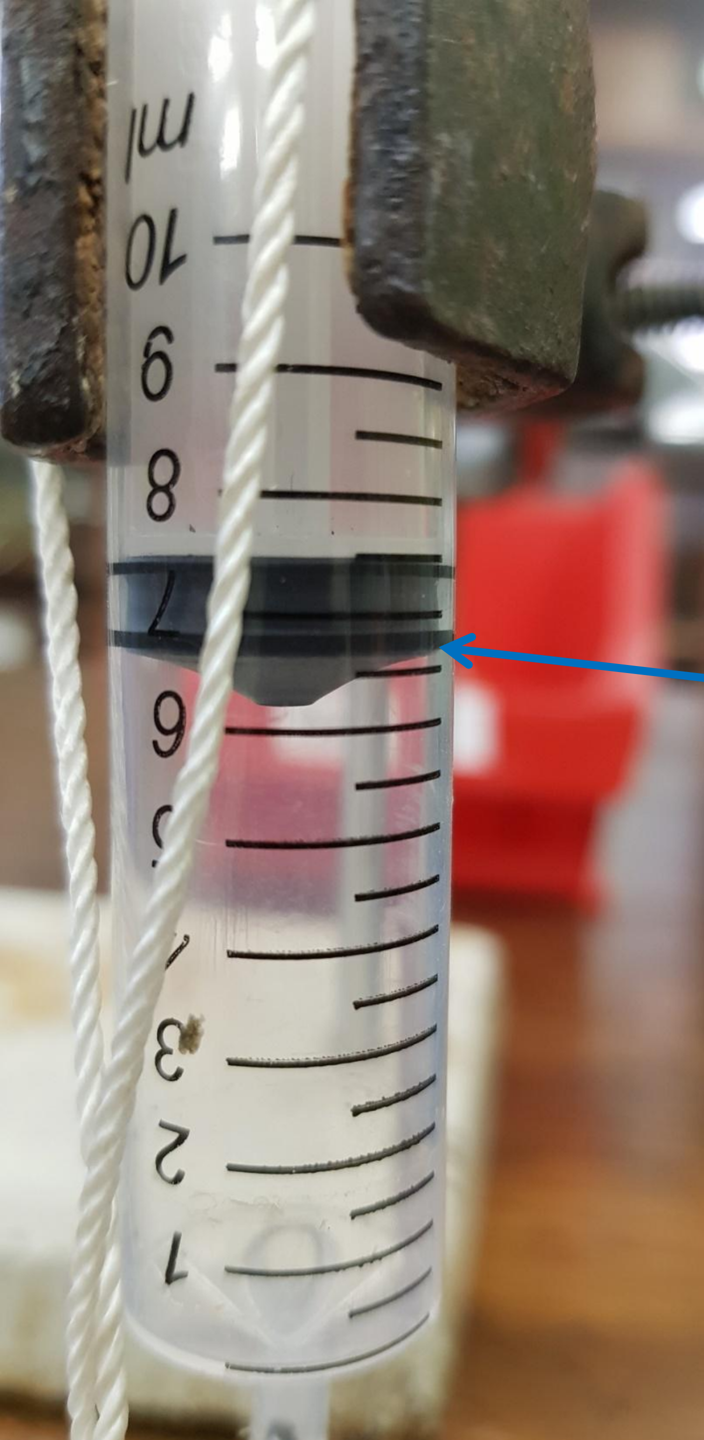
Basic idea:

Load the syringe plunger with masses to increase the air pressure in the syringe.

Record added mass vs syringe volume, using the (ml) scale printed on the syringe.

Syringe can get a 'bit sticky' so depress further than it needs to, and then let it rise to equilibrium.

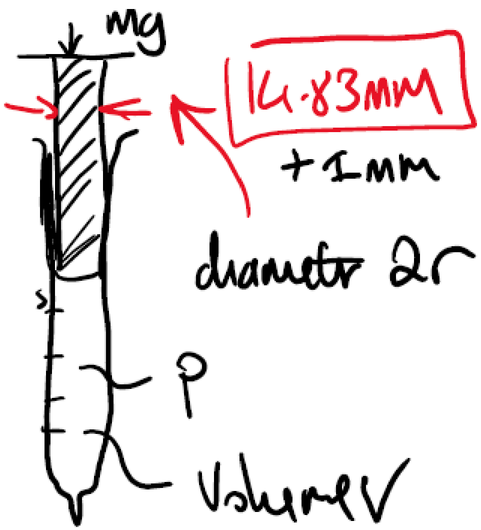




Read the gas volume in ml (1ml = 1cm^3) using the lower black line of the syringe plunger.

In this case about **6.7ml.**

Direct measurement of pressure, and relation to Boyle's law



The pressure p of the air is:

mass added /kg

$$p = p_0 + \frac{mg}{\pi r^2}$$

Strength of gravity 9.81N/kg

Atmospheric pressure /Pa

plunger radius /m

Boyle's law is a special case of the **Ideal Gas Equation**, when the number of moles of gas n is constant (i.e. assume the syringe doesn't leak) and the physical changes are *isothermal*, i.e. slow enough for the gas and ambient environment to be at the same temperature T.

$$pV = nRT = \text{constant}$$

$$\therefore pV = p_0 V_0$$

$$\therefore \left(p_0 + \frac{mg}{\pi r^2} \right) V = p_0 V_0$$

$$\left(p_0 + \frac{mg}{\pi r^2}\right)V = p_0 V_0$$

$$p_0 + \frac{mg}{\pi r^2} = \frac{p_0 V_0}{V}$$

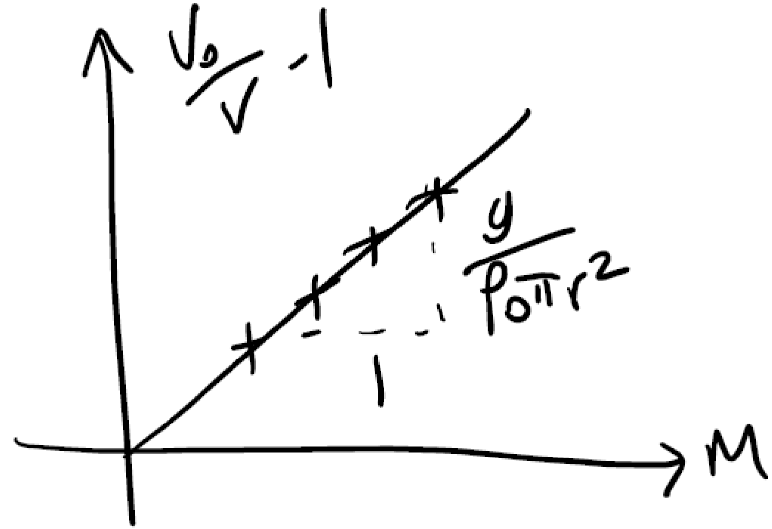
$$1 + \frac{mg}{\pi r^2 p_0} = \frac{V_0}{V}$$

$$\frac{mg}{\pi r^2 p_0} = \frac{V_0}{V} - 1$$

y

$$mk = y$$

Linearizing procedure



So plotting $\frac{V_0}{V} - 1$ vs added mass m

should yield a **straight line from the origin**.

If the gradient of this line is k, we can find the atmospheric pressure using:

$$k = \frac{g}{\pi r^2 p_0} \quad \therefore p_0 = \frac{g}{\pi r^2 k}$$

Recommended data collection and analysis is *directly into a spreadsheet*

$$p = p_0 + \frac{mg}{\pi r^2}$$

Get p_0 from an external barometer

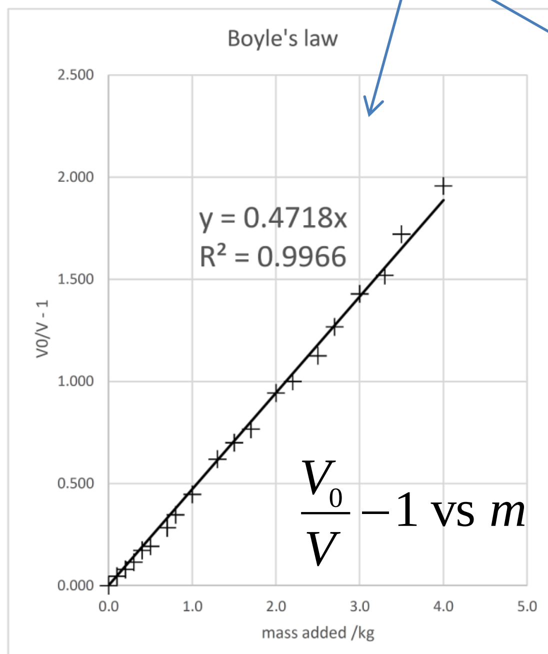
Graphs set up in advance to *plot as measurements are taken* – this helps choice of 'gap filler' measurements

BOYLE'S LAW USING SEALED SYRINGES

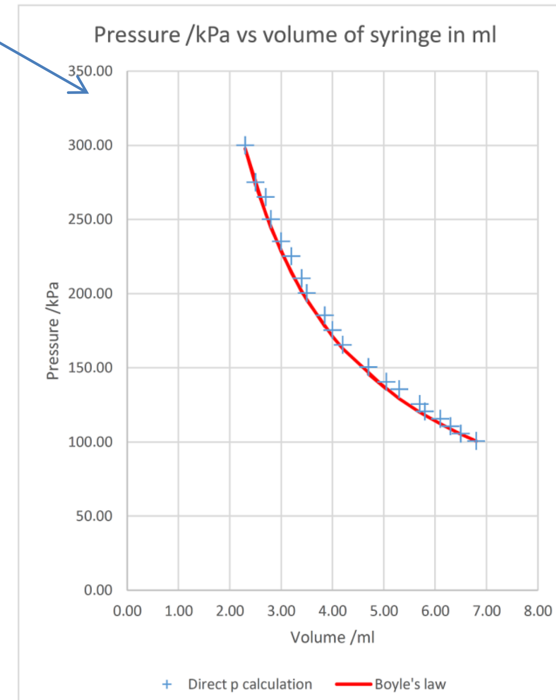
A. French. 10/10/2020. P5. Winchester College.

p0 /kPa
100.7

V /ml	Mass added /kg	V0/V - 1	Pressure /kPa	P = p0*V0/V /kPa
6.80	0.0	0.000	100.70	100.70
6.50	0.1	0.046	105.68	105.35
6.30	0.2	0.079	110.67	108.69
6.10	0.3	0.115	115.65	112.26
5.80	0.4	0.172	120.64	118.06
5.70	0.5	0.193	125.62	120.13
5.30	0.7	0.283	135.59	129.20
4.70	1.0	0.447	150.54	145.69
5.05	0.8	0.347	140.58	135.60
4.20	1.3	0.619	165.50	163.04
4.00	1.5	0.700	175.47	171.19
3.50	2.0	0.943	200.39	195.65
3.20	2.5	1.125	225.31	213.99
2.80	3.0	1.429	250.23	244.56
2.50	3.5	1.720	275.16	273.90
2.30	4.0	1.957	300.08	297.72
2.70	3.3	1.519	265.19	253.61
3.00	2.7	1.267	235.28	228.25
3.40	2.2	1.000	210.36	201.40
3.85	1.7	0.766	185.44	177.86



$$\frac{V_0}{V} - 1 \text{ vs } m$$



Syringe plunger diameter/mm 14.83

Note likely to be an underestimate, so a diameter of 15.83mm is assumed.

Measure this with the callipers. NOT the external diameter of the syringe! (Unless you know the wall thickness from an unsealed syringe).

$$p = \frac{p_0 V_0}{V}$$

$$p = p_0 + \frac{mg}{\pi r^2}$$

Start with 0.1kg increments, then move up to 0.5kg, then fill in gaps in the curves.

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p0 /kPa: 100.7

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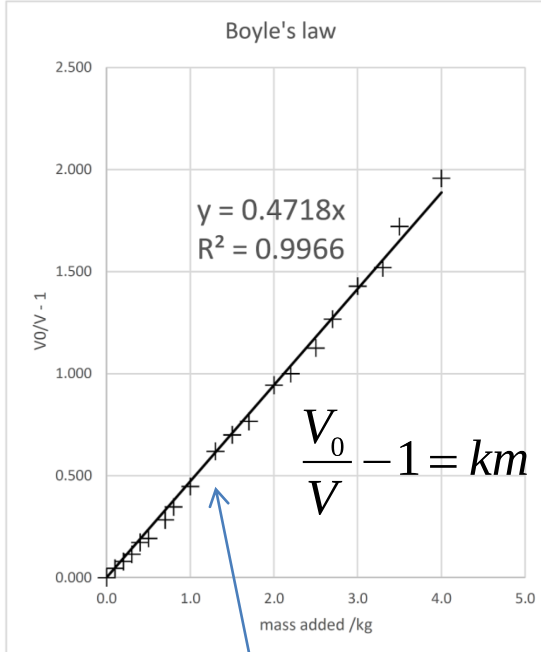
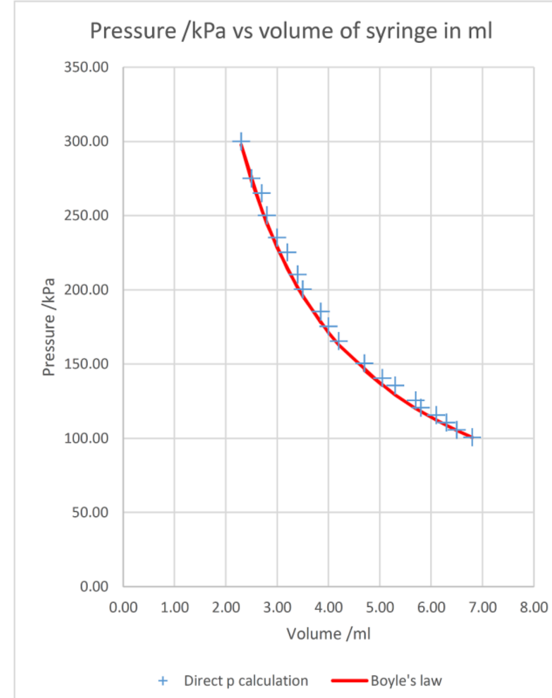


$$\frac{V_0}{V} - 1 = km$$



Very strong correlation of model to measurement, so Boyle's law can be deemed to be a valid model.

In this example:

$$k = 0.4718$$

$$\therefore p_0 = \frac{g}{\pi r^2 k} = \frac{9.81}{\pi\left(\tfrac{1}{2}15.83\times10^{-3}\right)^2 \times 0.4718} = 1.056\times10^5\,\text{Pa}$$

i.e. **105.6kPa** compared to the actual value of **100.7kPa**, about 5% off.