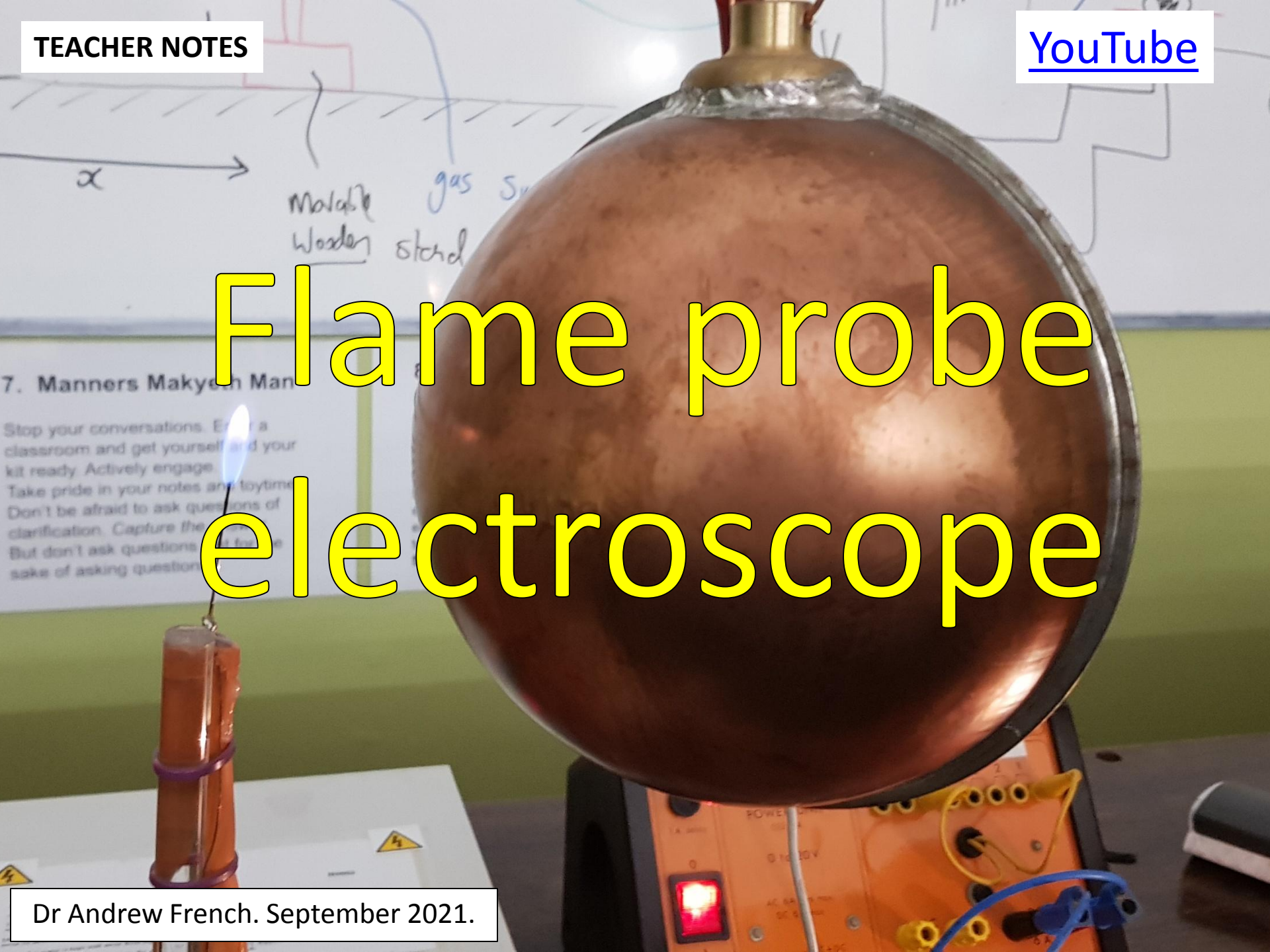
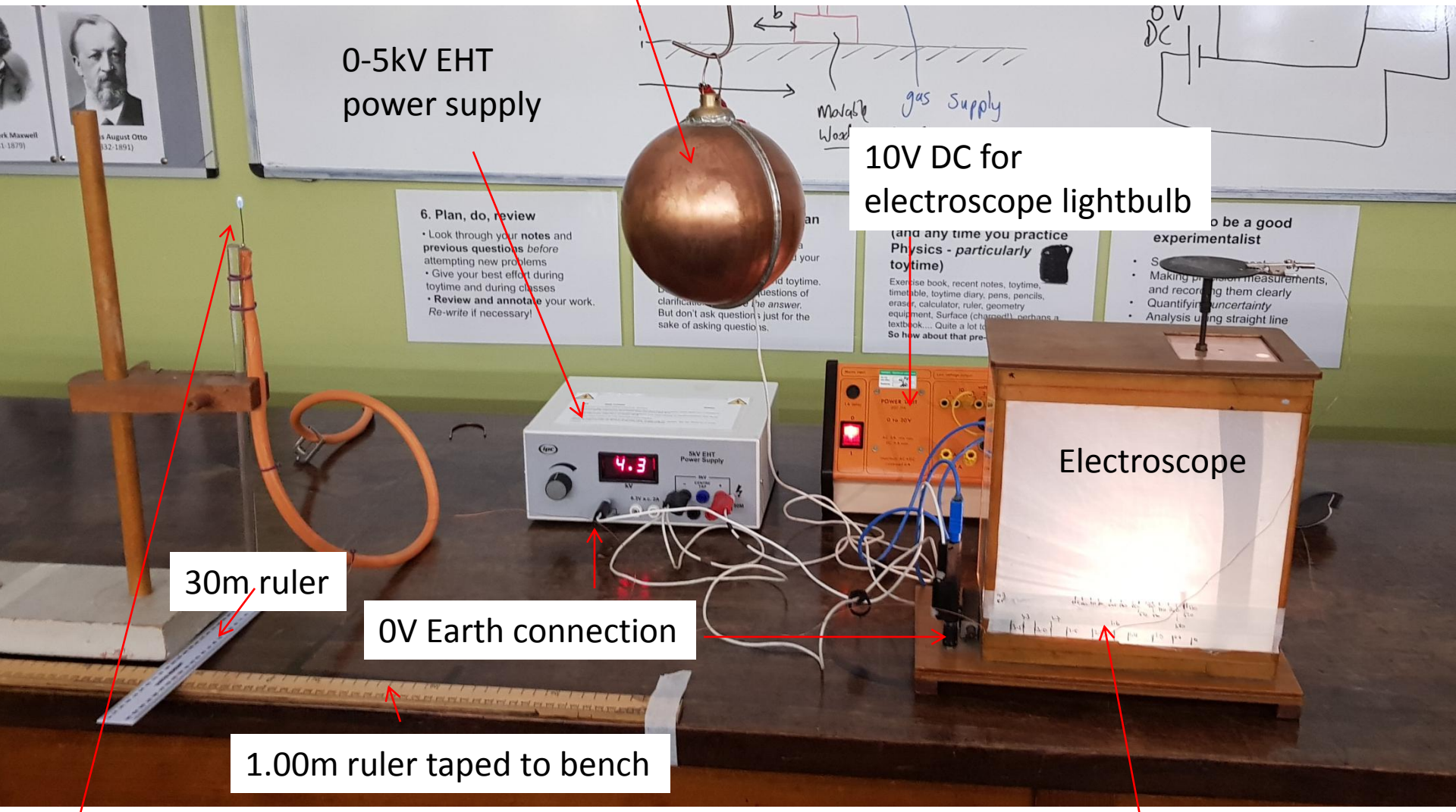
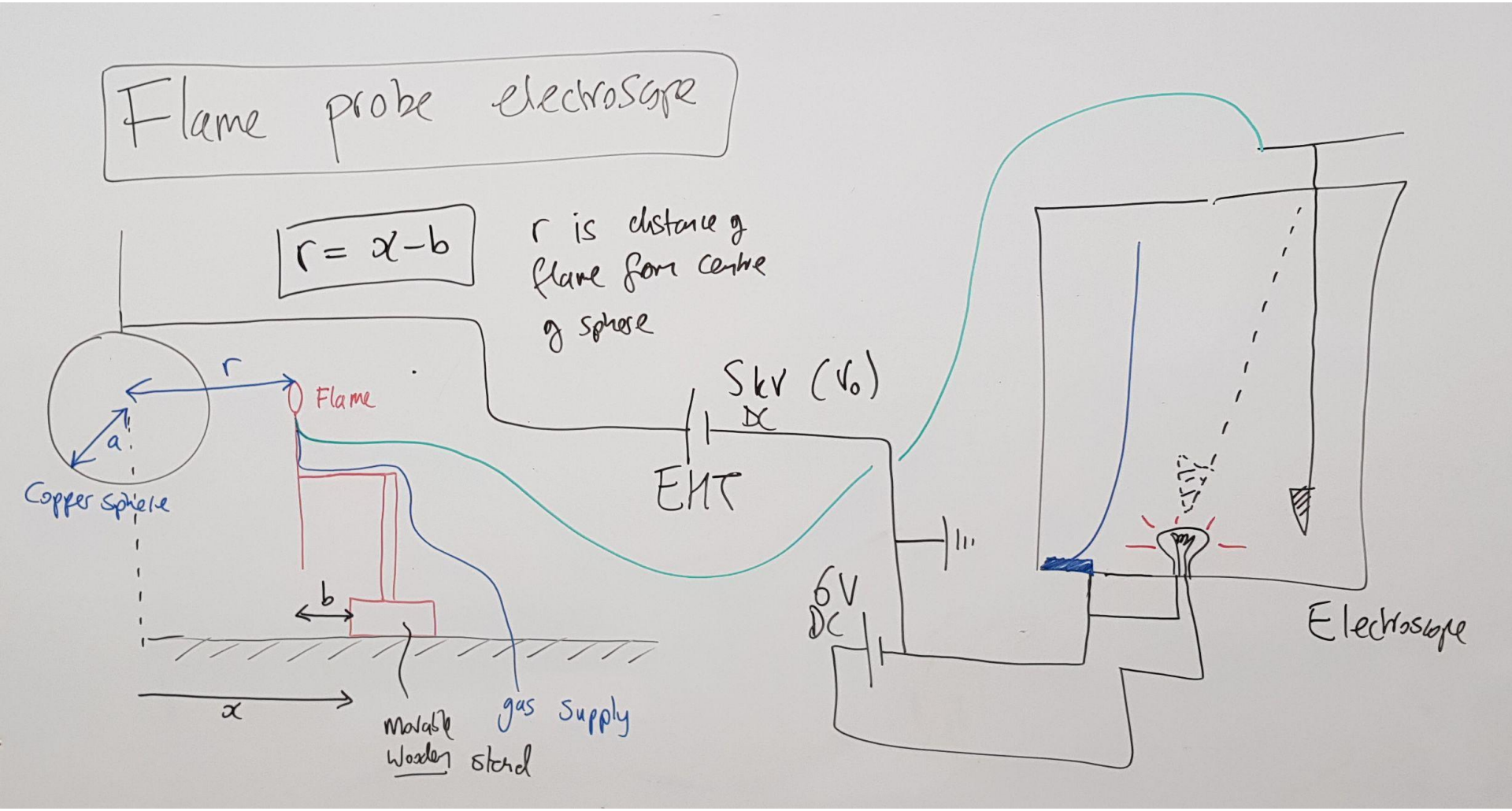
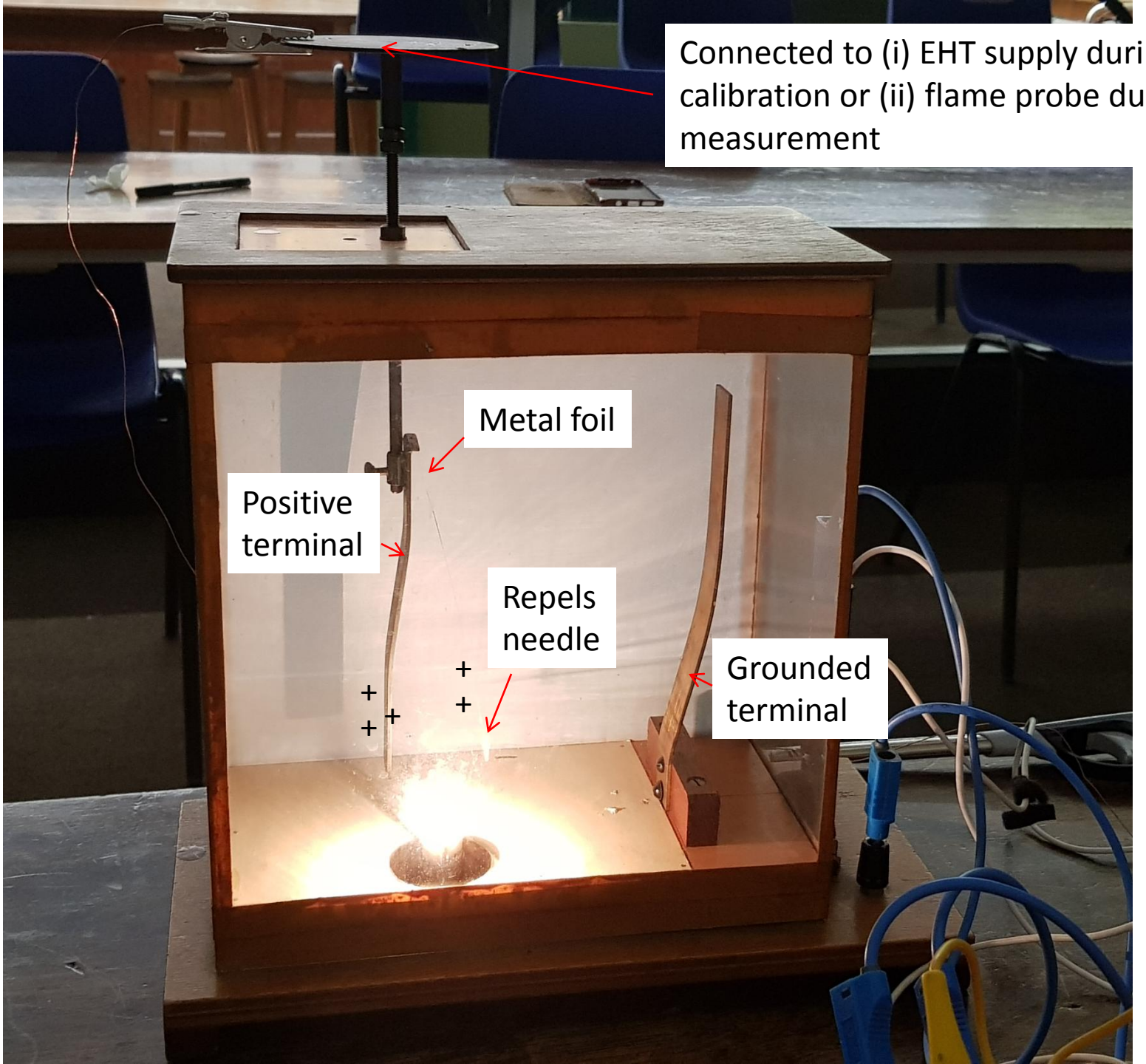

TEACHER NOTES
YouTube
Flame probe electroscope
Dr Andrew French. September 2021.

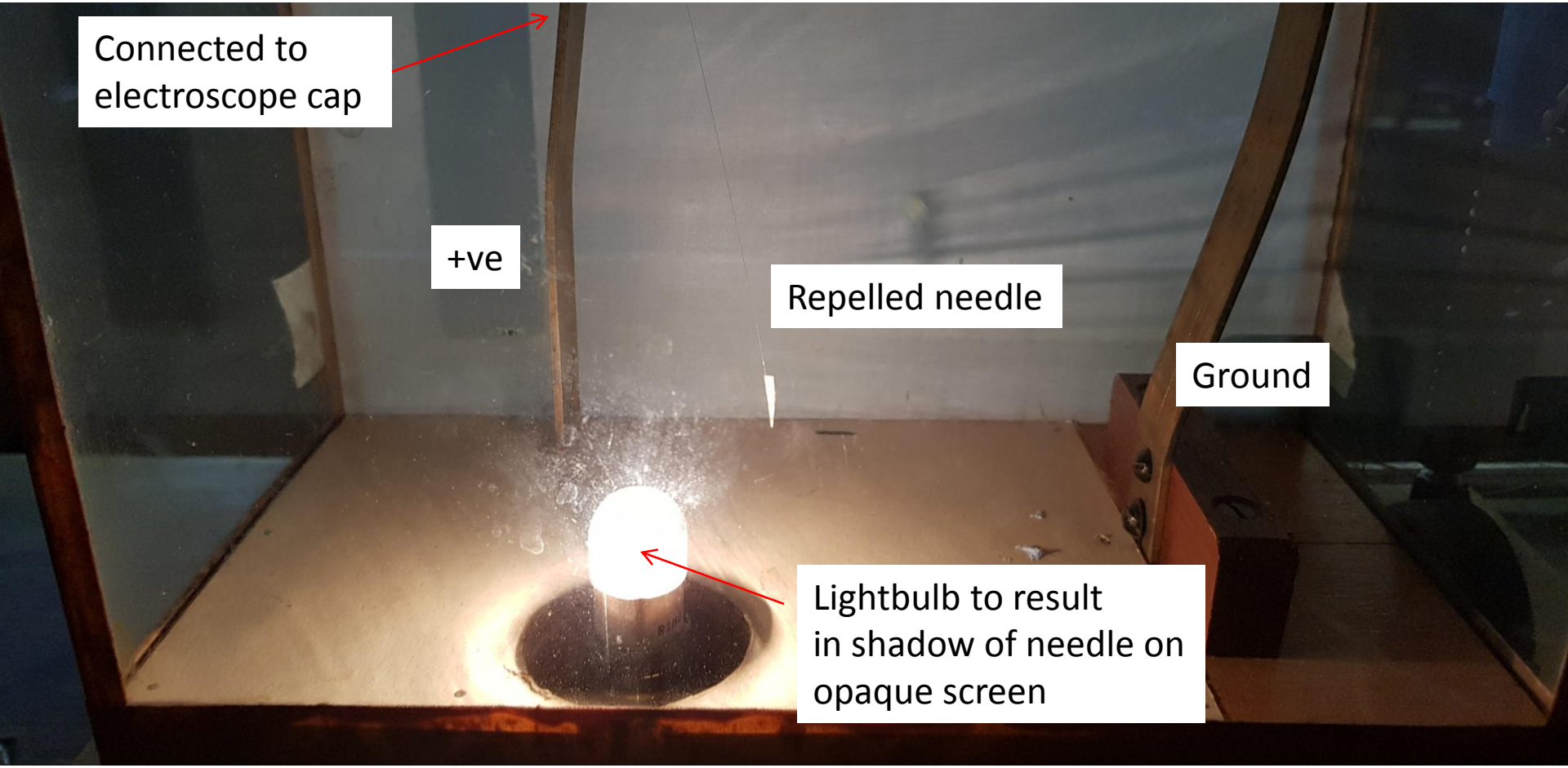

Copper sphere (radius about 7.5cm) suspended from a rope
0-5kV EHT power supply
10V DC for electroscope lightbulb
Electroscope
30m ruler
0V Earth connection
1.00m ruler taped to bench
Hyperdemic needle flame probe on wooden stand (connect to gas supply)
Calibration (lower) and measurements (upper) on masking tape strip.
6. Plan, do, review
• Look through your notes and previous questions before attempting new problems
• Give your best effort during toytime and during classes
• Review and annotate your work. Re-write if necessary!
5kV EHT Power Supply
4.3
gas Supply

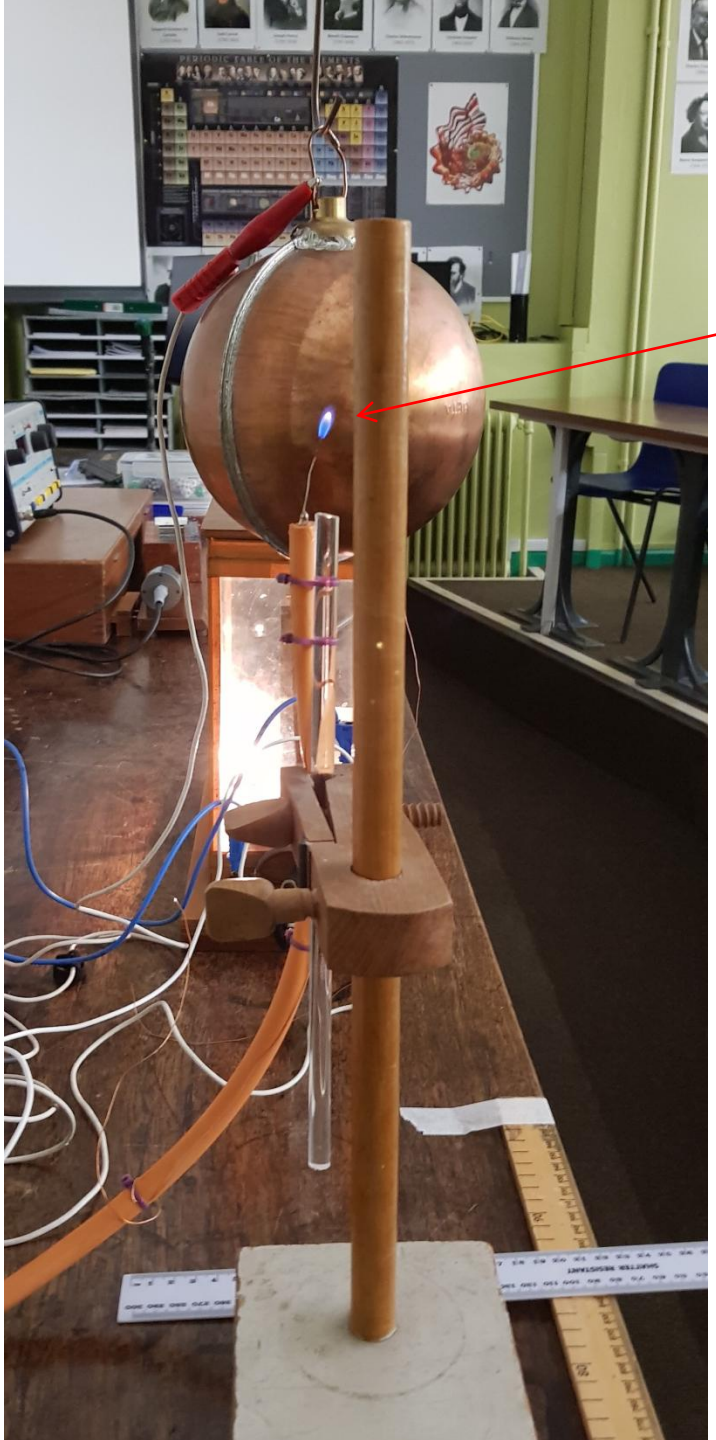
Schematic and circuit diagram for flame probe electroscope experiment



Goal: to show that the electric potential V varies *inversely* with distance r from the centre of an isolated charged sphere (when outside the sphere).

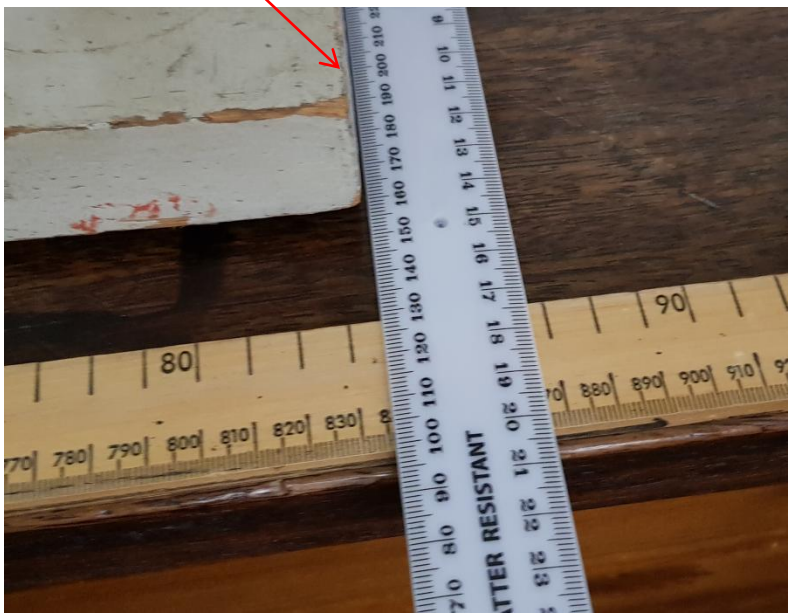

Connected to (i) EHT supply during calibration or (ii) flame probe during measurement
Metal foil
Positive terminal
Repels needle
Grounded terminal
+
+
+
+
+


Connected to electroscope cap
+ve
Repelled needle
Ground
Lightbulb to result in shadow of needle on opaque screen

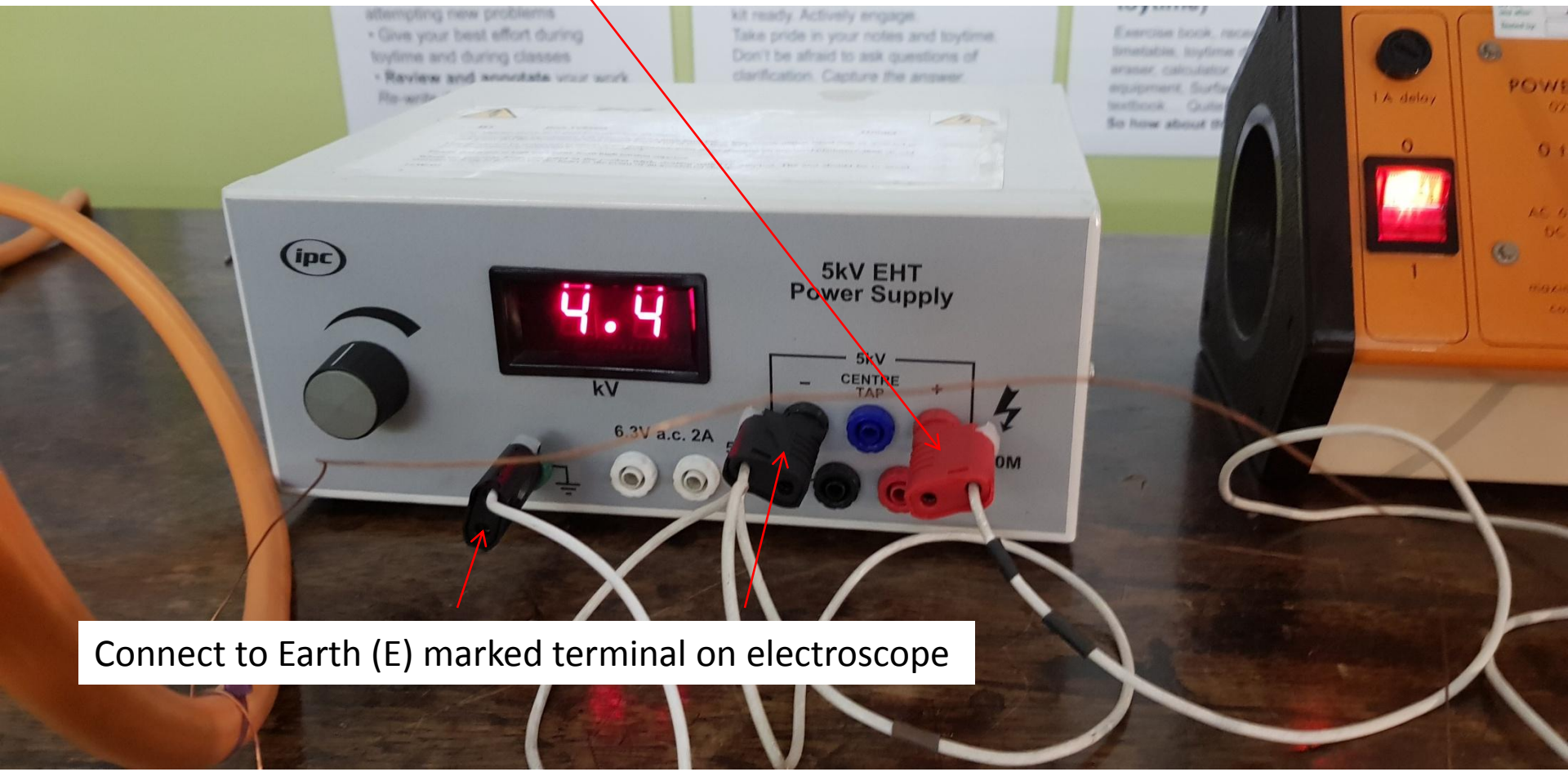


Align flame probe with centre of copper sphere.

Move wooden holder up to about 40cm away from the sphere (radius about 7.5cm). Measure using straight edge of holder base.

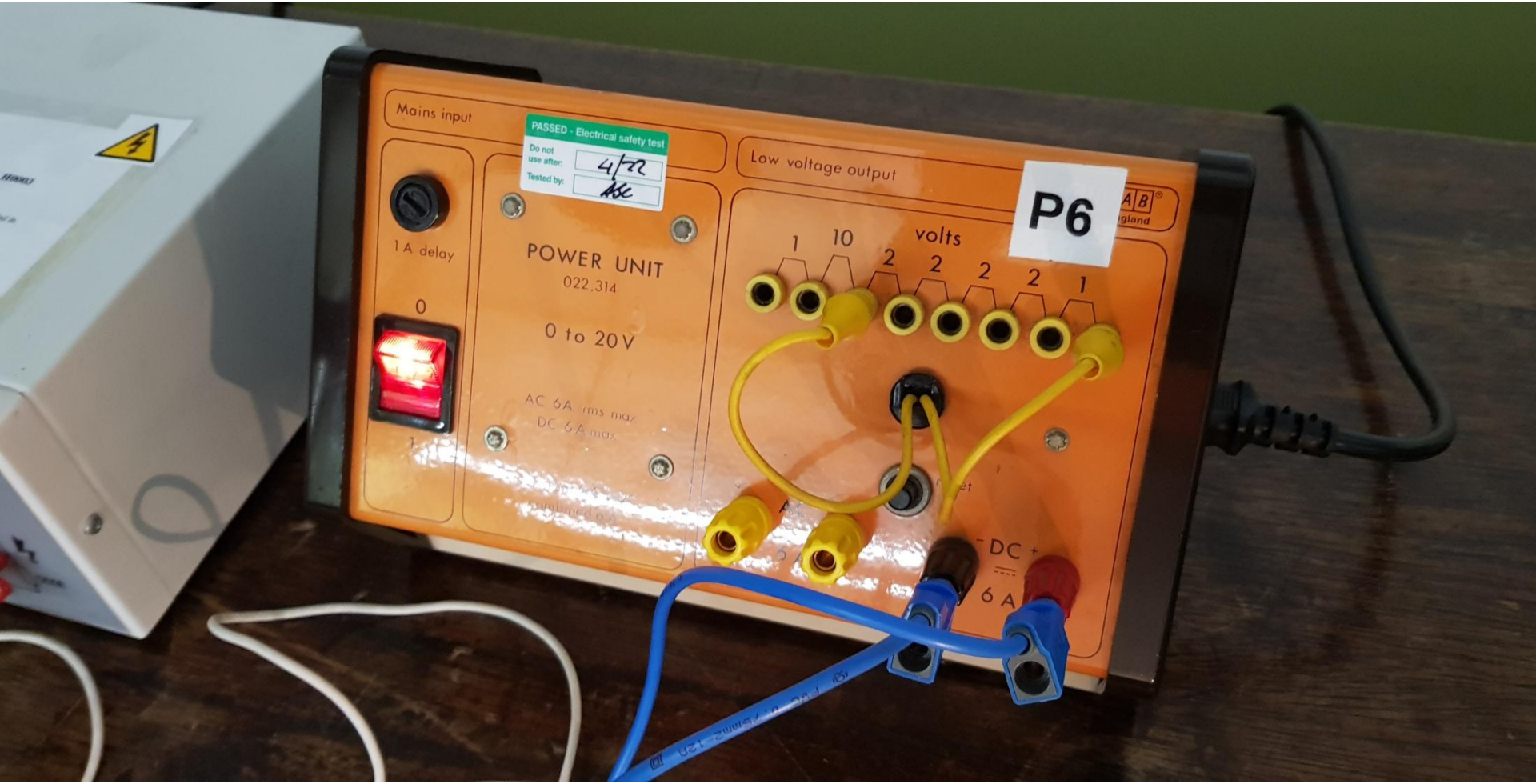


Use **shrouded connectors** to minimize possibility of high voltage shock



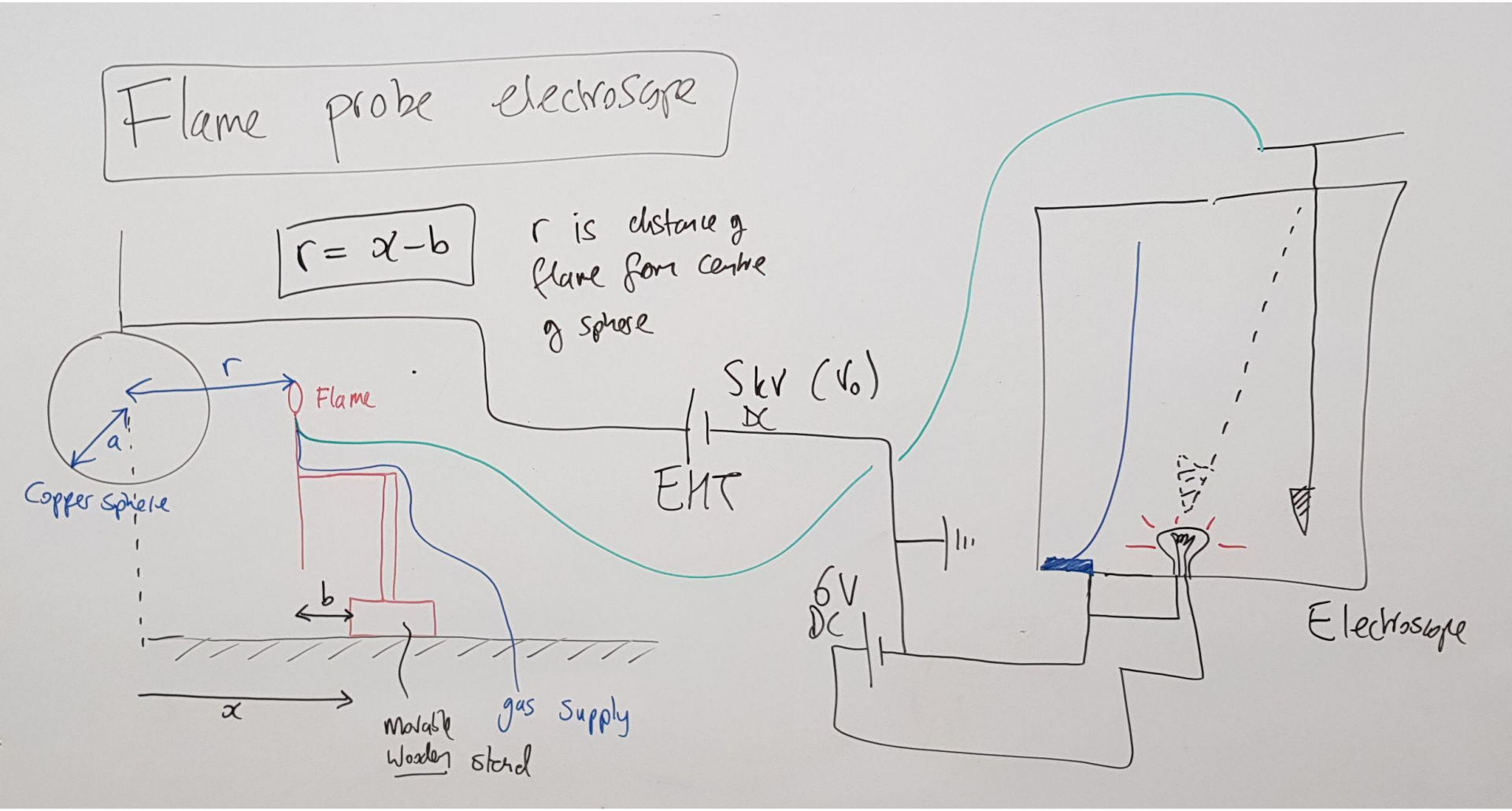
Connect to Earth (E) marked terminal on electroscope

Don’t connect across 10 mega-ohm resistors (i.e. the lower red and black terminals). The electroscope will leak charge a bit, and the charging time will be annoying long if you use the high resistances. You may find the electroscope needle can’t maintain its position at a given flame probe position otherwise.



About 10V DC to light up the electroscope bulb

Schematic and circuit diagram for flame probe electroscope experiment

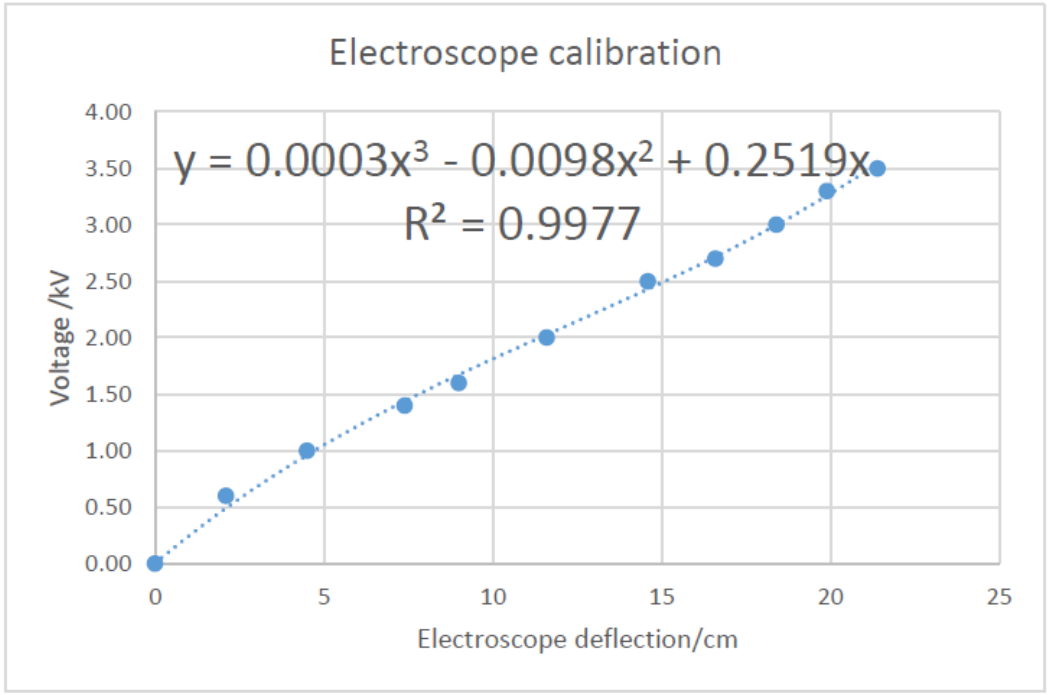


Goal: to show that the electric potential V varies *inversely* with distance r from the centre of an isolated charged sphere (when outside the sphere).

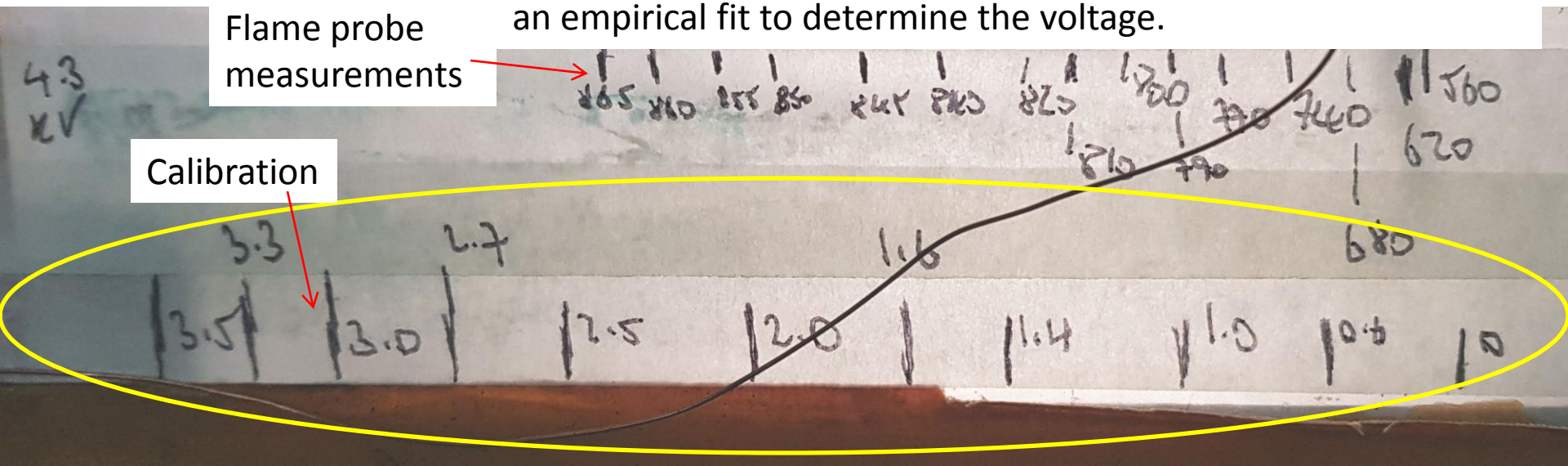
CALIBRATION

i.e. EHT supply connected directly to electroscope.

Electroscope deflection /cm	Voltage /kV
0	0.00
2.10	0.60
4.50	1.00
7.40	1.40
9.00	1.60
11.60	2.00
14.60	2.50
16.60	2.70
18.40	3.00
19.90	3.30
21.40	3.50



Photograph calibration and measurement electroscope deflection markings. Then measure off laptop screen and apply an empirical fit to determine the voltage.



FLAME PROBE ELECTROSCOPE
Dr French. 27/09/2021

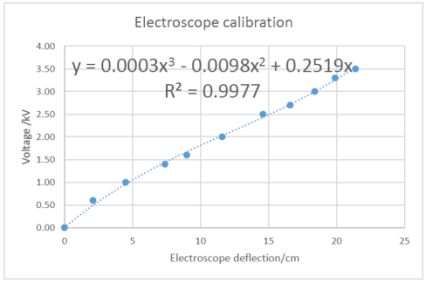
EHT voltage /kV: 4.3

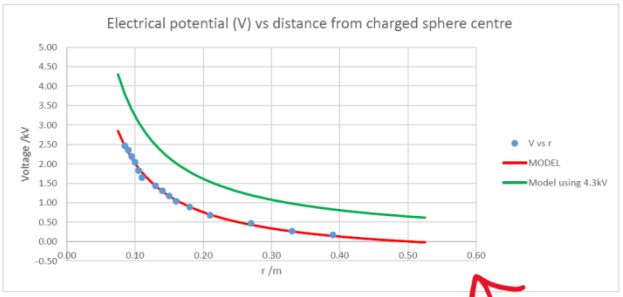
CALIBRATION
i.e. EHT supply connected directly to electroscope.

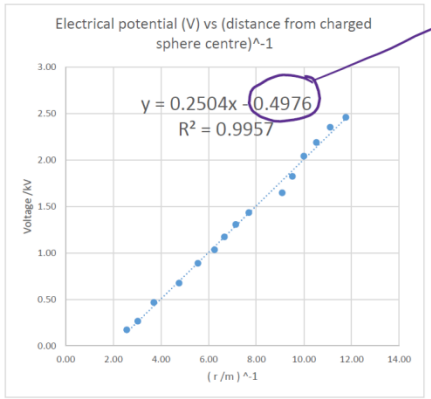
Electroscope deflection /cm	Voltage /kV
0	0.00
2.10	0.60
4.50	1.00
7.40	1.40
9.00	1.60
11.60	2.00
14.60	2.50
16.60	2.70
18.40	3.00
19.90	3.30
21.40	3.50

MEASUREMENT
i.e. connect EHT to copper sphere, and flame probe to electroscope.

Electroscope deflection /cm	Voltage /kV	x /mm	r /m	(r/m)^(-1)
14.20	2.46	865	0.09	11.76
13.50	2.35	860	0.09	11.11
12.40	2.19	855	0.10	10.53
11.40	2.04	850	0.10	10.00
9.90	1.82	845	0.11	9.52
8.70	1.65	840	0.11	9.09
7.30	1.43	820	0.13	7.69
6.50	1.31	810	0.14	7.14
5.70	1.17	800	0.15	6.67
4.90	1.03	790	0.16	6.25
4.10	0.89	770	0.18	5.56
3.00	0.68	740	0.21	4.76
2.00	0.47	680	0.27	3.70
1.10	0.27	620	0.33	3.03
0.70	0.17	560	0.39	2.56







MODEL of V /kV vs r/m

r /m	V /kV
0.075	2.842
0.085	2.449
0.095	2.139
0.105	1.888
0.115	1.681
0.125	1.506
0.135	1.358
0.145	1.230
0.155	1.119
0.165	1.021
0.175	0.934
0.185	0.856
0.195	0.787
0.205	0.724
0.215	0.668
0.225	0.616
0.235	0.568
0.245	0.525
0.255	0.485
0.265	0.448
0.275	0.413
0.285	0.381
0.295	0.352
0.305	0.324
0.315	0.298
0.325	0.273
0.335	0.250
0.345	0.228
0.355	0.208
0.365	0.189
0.375	0.170
0.385	0.153
0.395	0.137
0.405	0.121
0.415	0.106

Using V = 4.3kV*7.5e-2/(r/m)
4.300
3.794
3.395
3.071
2.804
2.580
2.389
2.224
2.081
1.955
1.843
1.743
1.654
1.573
1.500
1.433
1.372
1.316
1.265
1.217
1.173
1.132
1.093
1.057
1.024
0.992
0.963
0.935
0.908
0.884
0.860
0.838
0.816
0.796
0.777

Obviously this model breaks down when r becomes large, i.e. V can't be negative.

Also, $r \geq 7.5\times10^{-2}$ m
is outside sphere.

MODEL
$V = \frac{Q}{4\pi\varepsilon_0 r}$

Charged sphere
$C = 4\pi\varepsilon_0 a$
$Q = CV_0$

Systematic voltage offset?

$\therefore V = \frac{V_0 a}{r}$

i.e. $V_{measured} + 0.4976\,kV = \frac{0.2504}{r}$

so $V_0 a = 0.2504$

$a = 7.5\times10^{-2}$ m

$\therefore V_0 = \frac{0.2504\ kV}{7.5\times10^{-2}}$

$= 3.34\ kV$

$V/kV = \frac{3.34 \times 7.5\times10^{-2}\ m}{(r/m)} - 0.498$

Good fit to $\frac{1}{r}$ model
BUT only with -0.498 kV offset and much lower Sphere Voltage (3.34kV) than EHT Supply (4.30 kV).

EHT Volt Supp

2021

FLAME PROBE ELECTROSCOPE
Dr French. 27/09/2021

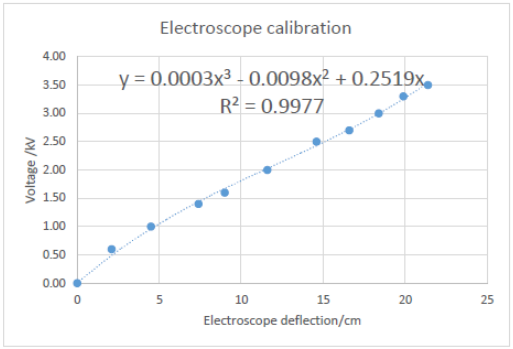
EHT voltage /kV 4.3

CALIBRATION
i.e. EHT supply connected directly to electroscope.

MEASUREMENT
i.e. connect EHT to copper sphere, and flame probe to electroscope.

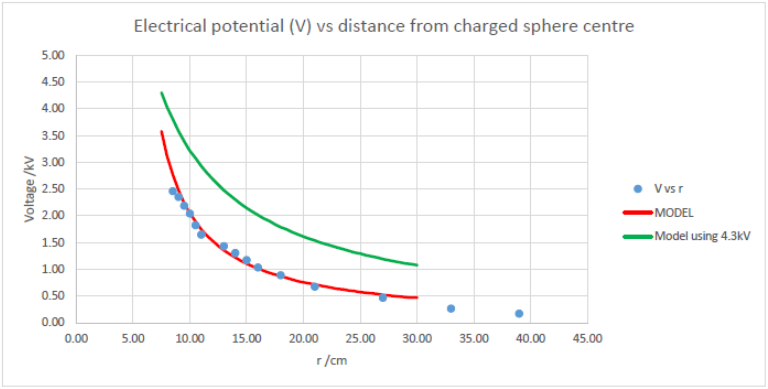
Electroscope deflection /cm	Voltage /kV
0	0.00
2.10	0.60
4.50	1.00
7.40	1.40
9.00	1.60
11.60	2.00
14.60	2.50
16.60	2.70
18.40	3.00
19.90	3.30
21.40	3.50

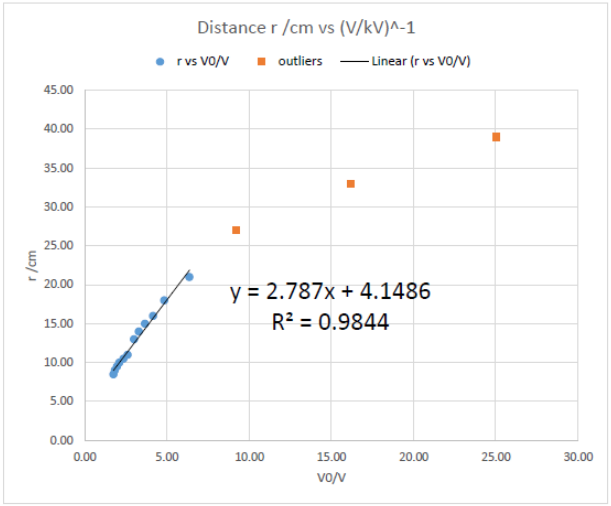
Electroscope deflection /cm	Voltage /kV	x /mm	r /cm	V0/V
14.20	2.46	865	8.50	1.75
13.50	2.35	860	9.00	1.83
12.40	2.19	855	9.50	1.96
11.40	2.04	850	10.00	2.11
9.90	1.82	845	10.50	2.36
8.70	1.65	840	11.00	2.61
7.30	1.43	820	13.00	3.00
6.50	1.31	810	14.00	3.29
5.70	1.17	800	15.00	3.67
4.90	1.03	790	16.00	4.16
4.10	0.89	770	18.00	4.84
3.00	0.68	740	21.00	6.36
2.00	0.47	680	27.00	9.21
1.10	0.27	620	33.00	16.19
0.70	0.17	560	39.00	25.05



$$Q = CV$$
$$C = 4\pi\varepsilon_0 a, \quad V = V_0 = 4.3\text{kV}$$
$$V = \frac{Q}{4\pi\varepsilon_0}\frac{1}{r} \qquad r \geq a \qquad a = 7.5\text{cm}$$
$$\therefore V = \frac{V_0 a}{r}$$
$$\therefore r = a\frac{V_0}{V}$$

Using electric potential of a sphere and capacitance of a sphere.





MODEL of V /kV vs r/m

r /cm	V /kV
7.5	3.581
8	3.116
8.5	2.758
9	2.474
9.5	2.242
10	2.051
10.5	1.889
11	1.751
11.5	1.632
12	1.528
12.5	1.437
13	1.356
13.5	1.283

Using V = 4.3kV*(7.5cm/r)
4.300
4.031
3.794
3.583
3.395
3.225
3.071
2.932
2.804
2.688
2.580
2.481
2.389

$$(r/cm) = 2.79 \times \frac{4.3}{V/\text{kV}} + 4.15$$
$$\therefore r - 4.15\text{cm} = 2.79 \times \frac{4.3}{V/\text{kV}}$$
$$\therefore V = 4.3\text{kV} \times \frac{2.79\text{cm}}{r - 4.15\text{cm}}$$

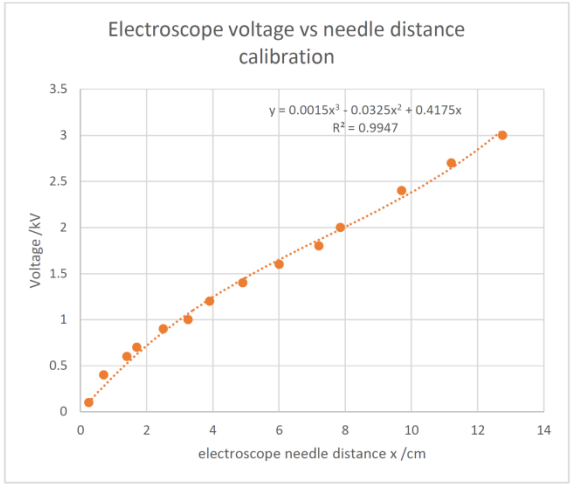
This system is behaving like a 2.79cm radius sphere (rather than 7.5cm) but our measured radii are 4.15cm too large.

Alternative analysis 2021

CHARGED SPHERE FLAME PROBE
21/09/2020

CALIBRATION

V/kV	x /cm
0.1	0.25
0.4	0.7
0.6	1.4
0.7	1.7
0.9	2.5
1	3.25
1.2	3.9
1.4	4.9
1.6	6
1.8	7.2
2	7.85
2.4	9.7
2.7	11.2
3	12.75

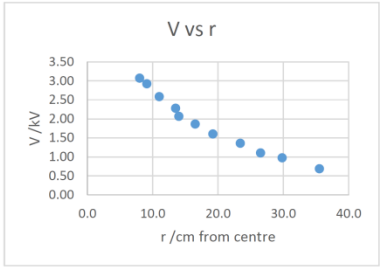


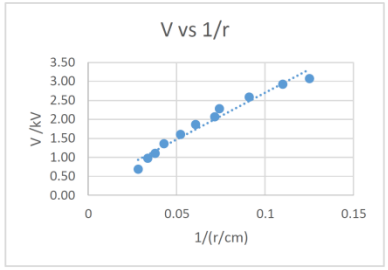
FLAME PROBE EXPERIMENT

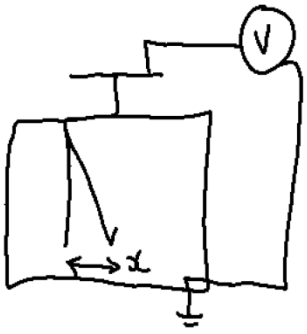
Needle deflection x /cm
12.5
12
10.7
9.3
8.2
7.1
5.7
4.5
3.4
2.9
1.9

V /kV	distance r of flame from sphere
3.07	8.0
2.92	9.1
2.58	11.0
2.28	13.5
2.07	14.0
1.86	16.5
1.60	19.2
1.36	23.4
1.10	26.5
0.97	29.8
0.69	35.5

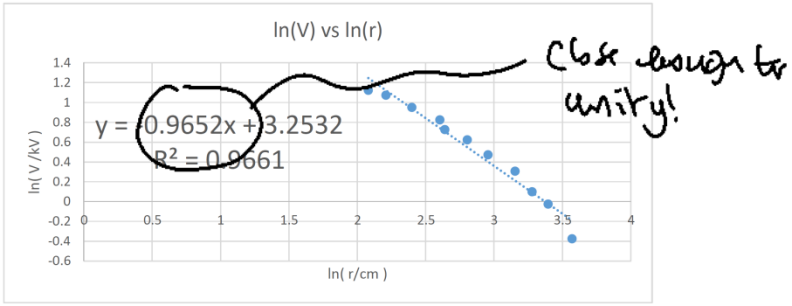
1/r	ln(r)	ln(V)
0.125	2.079442	1.121779
0.10989	2.208274	1.072268
0.090909	2.397895	0.949296
0.074074	2.60269	0.823456
0.071429	2.639057	0.725252
0.060606	2.80336	0.622076
0.052083	2.95491	0.471012
0.042735	3.152736	0.305507
0.037736	3.277145	0.097813
0.033557	3.394508	-0.02634
0.028169	3.569533	-0.37657



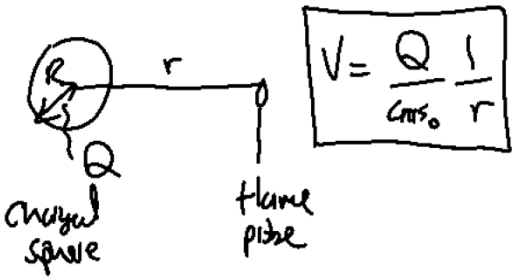




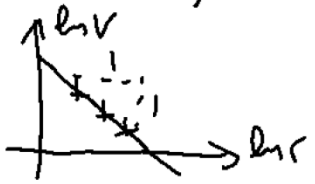
Electroscope.



MODEL



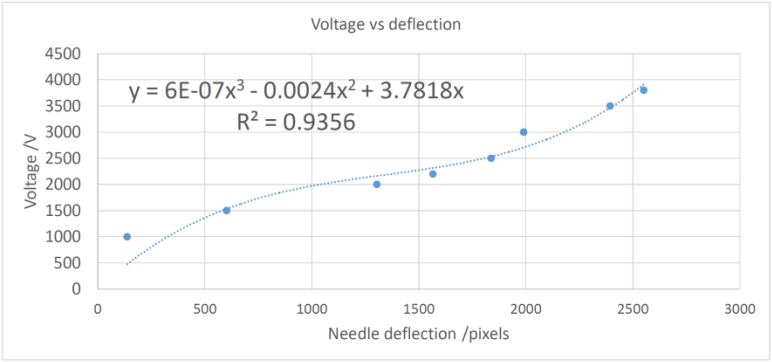
$\ln V = \ln\left(\frac{Q}{4\pi\varepsilon_0}\right) - \ln r$



Electroscope calibration 26/9/2019

2019

Supply voltage /V	deflection /pixel from photo
3800	2551
3500	2394
3000	1990
2500	1838
2200	1566
2000	1304
1500	602
1000	137

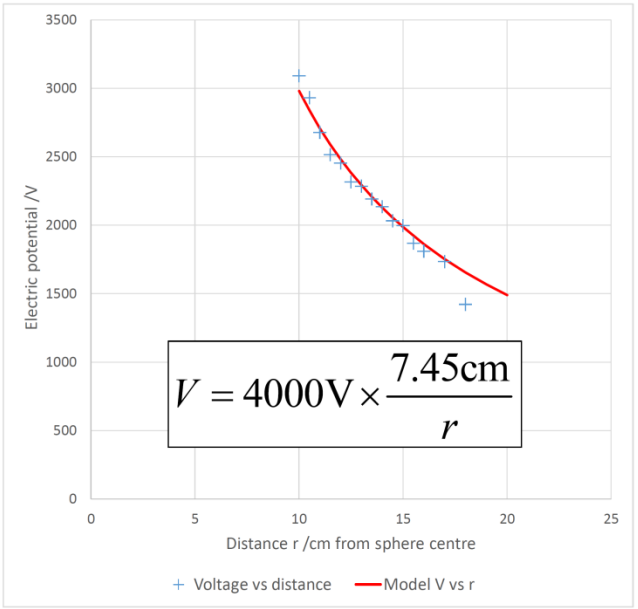


Flame probe experiment

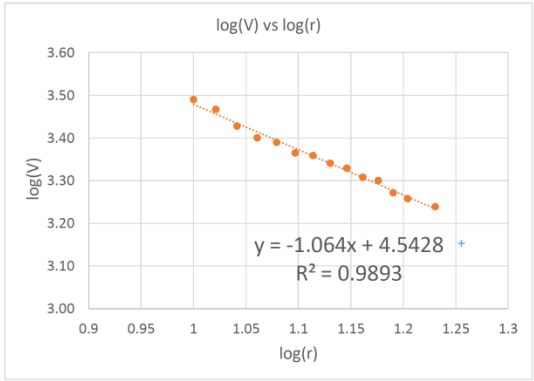
Sphere radius a /cm
7.45

Sphere voltage V0 /V
4000

Needle from sphere centre (r) /cm	Needle deflection /pixels	Voltage /V	log r	log V	MODEL V
10	2199	3091	1	3.49	2980.00
10.5	2110	2931	1.021189	3.47	2838.10
11	1934	2677	1.041393	3.43	2709.09
11.5	1783	2514	1.060698	3.40	2591.30
12	1715	2453	1.079181	3.39	2483.33
12.5	1528	2316	1.09691	3.36	2384.00
13	1479	2285	1.113943	3.36	2292.31
13.5	1322	2191	1.130334	3.34	2207.41
14	1225	2134	1.146128	3.33	2128.57
14.5	1067	2032	1.161368	3.31	2055.17
15	1019	1996	1.176091	3.30	1986.67
15.5	870	1869	1.190332	3.27	1922.58
16	812	1810	1.20412	3.26	1862.50
17	745	1733	1.230449	3.24	1752.94
18	531	1421	1.255273	3.15	1655.56
19	318	979	1.278754	2.99	1568.42
20	157	537	1.30103	2.73	1490.00



$$Q = CV_0$$
$$C = 4\pi\varepsilon_0 a$$
$$\therefore Q = 4\pi\varepsilon_0 a V_0$$
$$V = \frac{Q}{4\pi\varepsilon_0 r}$$
$$\therefore V = \frac{V_0 a}{r}$$
$$\log V = \log(V_0 a) - \log r$$



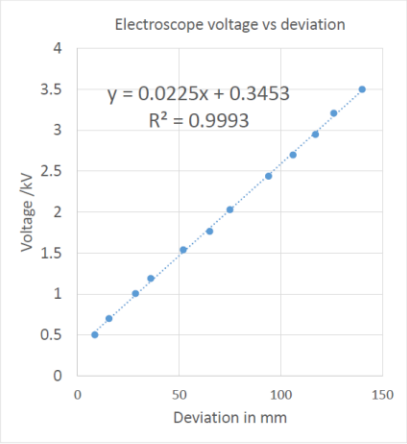
$$\log(V_0 a) = 4.5428$$
$$V_0 = \frac{10^{4.5428}}{7.45} \approx 4680\text{V}$$

Actual voltage was about 4000V

2018

Electroscope calibration 18/9/2018

Supply voltage /kV	Voltage of voltmeter /V	Voltmeter supply potential /kV	Electroscope deviation /mm
0.5	100	0.5	8.5
0.7	140	0.7	15.5
1	201	1.005	28.5
1.2	238	1.19	36
1.5	308	1.54	52
1.8	353	1.765	65
2	406	2.03	75
2.5	488	2.44	94
2.7	540	2.7	106
3	590	2.95	117
3.2	642	3.21	126
3.5	700	3.5	140



Flame probe experiment

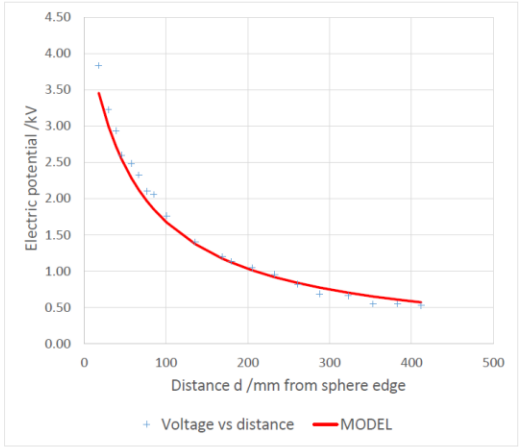
Sphere radius a /mm
59.5

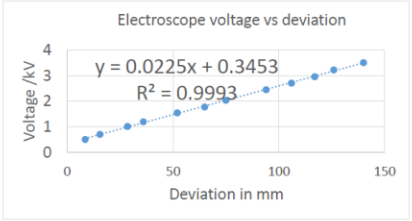
Sphere voltage V0 /kV
4.5

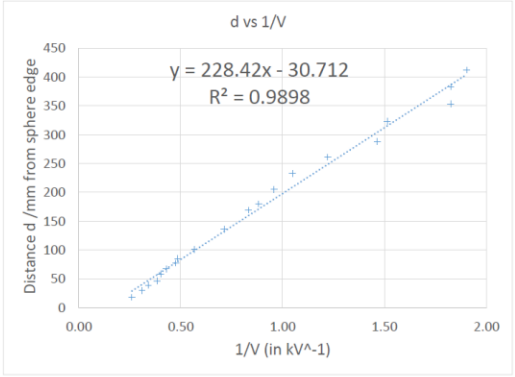
Capacitor efficiency k
1

$$Q = CV_0$$
$$C = 4\pi\varepsilon_0 a \times k$$
$$\therefore Q = 4\pi\varepsilon_0 a V_0 k$$
$$V = \frac{Q}{4\pi\varepsilon_0 (a+d)}$$
$$\therefore V = \frac{V_0 ka}{a+d}$$
$$\therefore d = \frac{V_0 ka}{V} - a$$

Distance sphere edge to flame /mm	d error /mm	Electroscope deviation /mm	deviation error /mm	Voltage /kV	1/V	MODEL V /kV
18	0.5	155	5	3.83	0.26	3.45
30	0.5	128	5	3.23	0.31	2.99
39	0.5	115	5	2.93	0.34	2.72
46	0.5	100	3	2.60	0.39	2.54
58	0.5	95	3	2.48	0.40	2.28
67	0.5	88	3	2.33	0.43	2.12
77	0.5	78	3	2.10	0.48	1.96
85	0.5	76	3	2.06	0.49	1.85
101	0.5	63	3	1.76	0.57	1.67
136	0.5	47	3	1.40	0.71	1.37
169	0.5	38	2	1.20	0.83	1.17
180	0.5	35	2	1.13	0.88	1.12
205	0.5	31	2	1.04	0.96	1.01
233	0.5	27	2	0.95	1.05	0.92
261	0.5	21	2	0.82	1.22	0.84
288	0.5	15	1	0.68	1.46	0.77
323	1	14	1	0.66	1.51	0.70
353	1	9	1	0.55	1.83	0.65
383	1	9	1	0.55	1.83	0.61
412	1	8	1	0.53	1.90	0.57



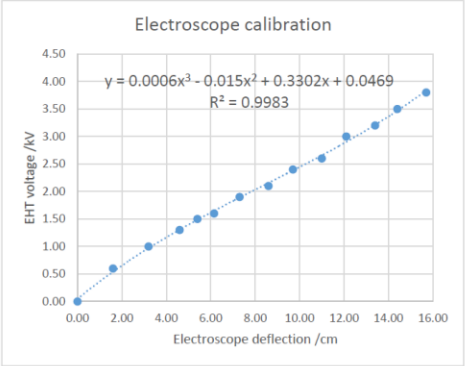


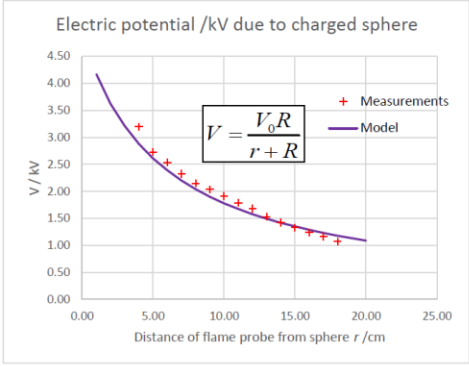


2017

Calibration by charging electroscope from DC 'High Tension' supply
19th October 2017. AF & 5P3. P5. Winchester College.

V /kV	Electroscope deflection (x) /cm
0.00	0.00
0.60	1.60
1.00	3.20
1.30	4.60
1.50	5.40
1.60	6.15
1.90	7.30
2.10	8.60
2.40	9.70
2.60	11.00
3.00	12.10
3.20	13.40
3.50	14.40
3.80	15.70

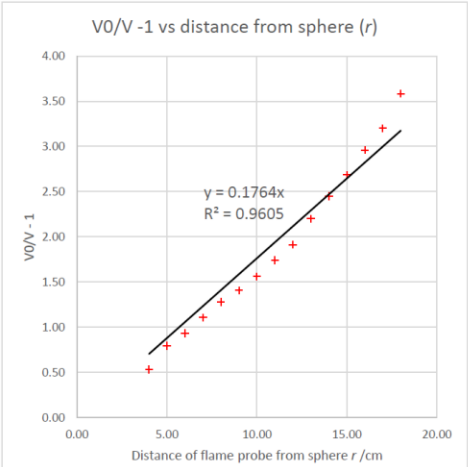




Measurements using charged sphere (4.9kV)

Distance of flame probe from edge of sphere (r) /cm	Electroscope deflection /cm	Voltage	V0/V - 1
3.00	14.70	3.57	0.37
4.00	13.30	3.20	0.53
5.00	11.30	2.73	0.80
6.00	10.40	2.53	0.93
7.00	9.40	2.32	1.11
8.00	8.55	2.15	1.28
9.00	8.00	2.04	1.41
10.00	7.40	1.91	1.56
11.00	6.80	1.79	1.74
12.00	6.30	1.68	1.91
13.00	5.60	1.53	2.20
14.00	5.10	1.42	2.45
15.00	4.70	1.33	2.68
16.00	4.30	1.24	2.96
17.00	4.00	1.17	3.20
18.00	3.60	1.07	3.58
20.00	3.00	0.92	4.33
22.00	2.10	0.68	6.21
24.00	1.80	0.60	7.22
30.00	1.20	0.42	10.60
35.00	1.00	0.36	12.51
40.00	0.85	0.32	14.45

Ignore last few readings (yellow). Misalignment of flame from copper sphere central axis.



$$Q = CV_0$$
$$C = 4\pi\varepsilon_0 R$$
$$\therefore Q = 4\pi\varepsilon_0 R V_0$$
$$V = \frac{Q}{4\pi\varepsilon_0 (r+R)}$$
$$\therefore V = \frac{V_0 R}{r+R}$$
$$\therefore \frac{V_0}{V} = \frac{r+R}{R}$$
$$\therefore \frac{V_0}{V} - 1 = \frac{r}{R}$$

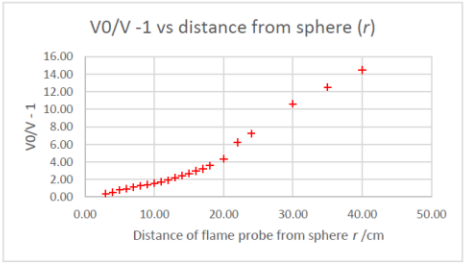
Predicted radius R of sphere /cm is reciprocal of gradient
5.7

Sphere radius is about 5cm (direct measurement)

Model

V0 /kV	4.9	R /cm	5.7

r /cm	V /kV
1	4.17
2	3.63
3	3.21
4	2.88
5	2.61
6	2.39
7	2.20
8	2.04
9	1.90
10	1.78
11	1.67
12	1.58
13	1.49
14	1.42
15	1.35
16	1.29
17	1.23
18	1.18
19	1.13
20	1.09



Or other effects, such as proximity of metal in bench?