TEACHER NOTES

Youtube video

Half life of Protactinium

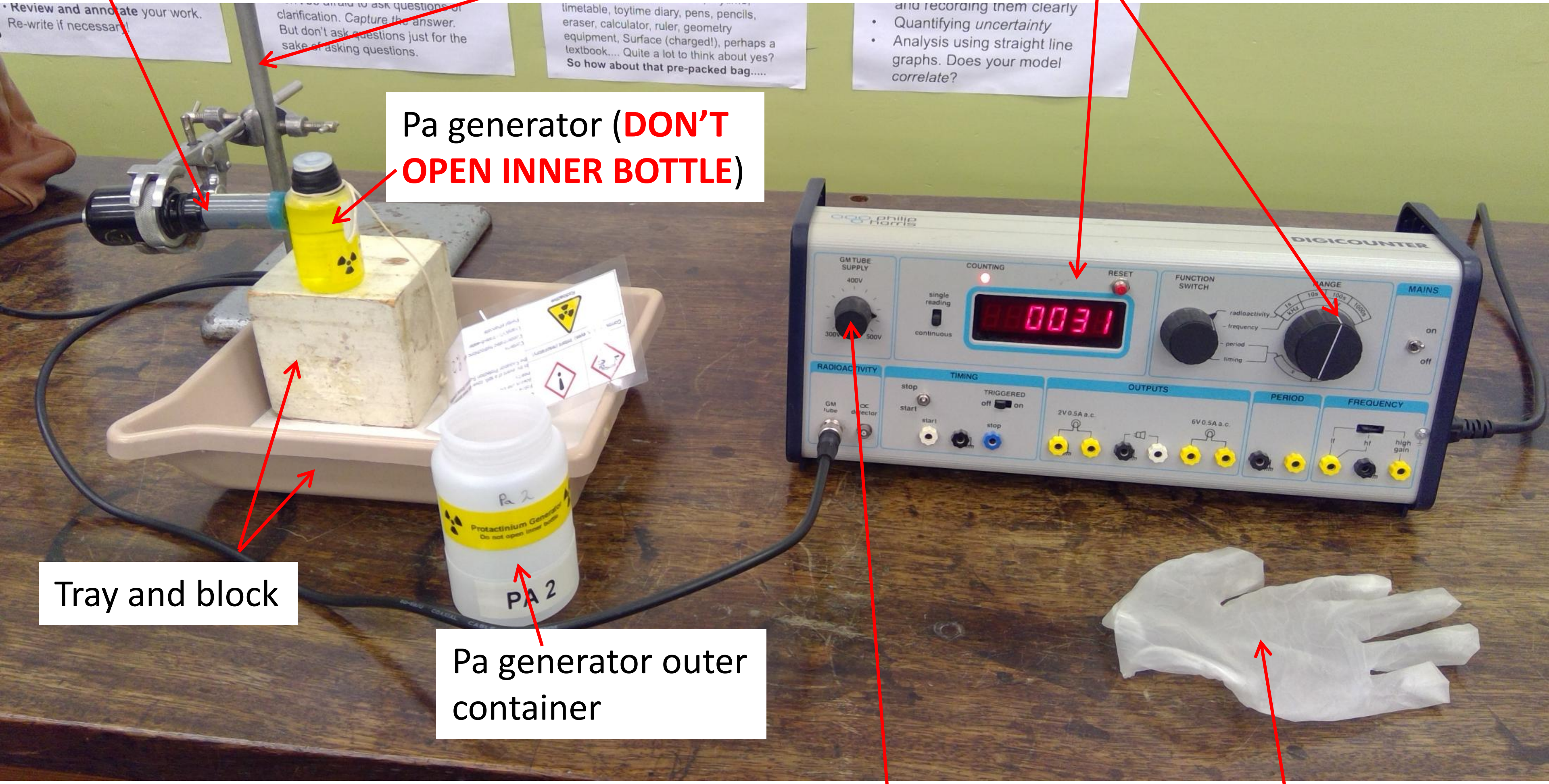
Dr Andrew French. September 2021.

Equipment

Geiger-Muller (GM) tube

Retort stand to hold GM tube steady

Radioactivity counter (set **counts per 100s** for background, and **counts per 10s** during Pa decay experiment).



Pa generator (**DON'T OPEN INNER BOTTLE**)

Tray and block

Pa generator outer container

About 450V to enable radiation counts from the GM tube

Gloves for handling Pa generator

Always transport the Pa generator back to the store cupboard via the ‘Radiation bucket.’

Teachers: Always sign out (and then sign in) the Pa generator from the store cupboard.

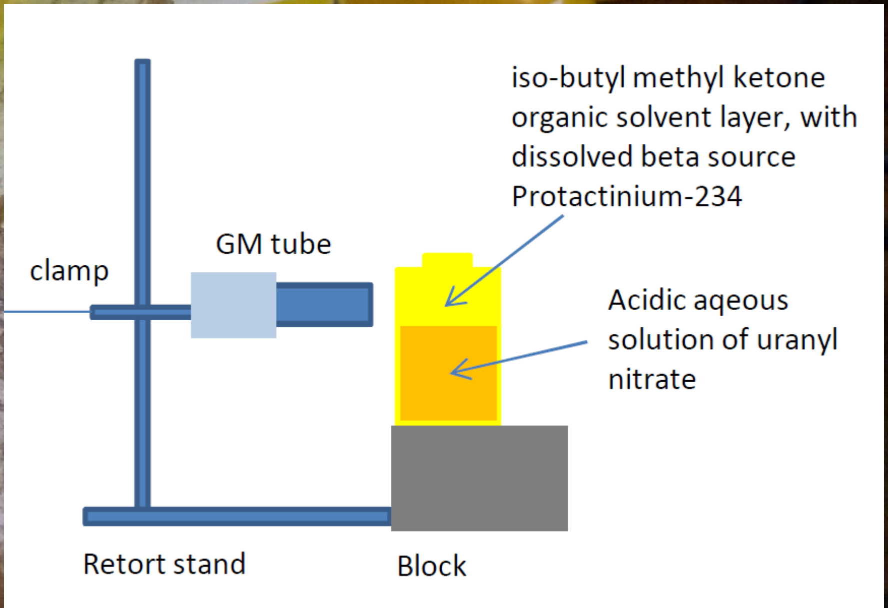
Make sure you point the GM tube in the middle of the *upper* layer of liquid in the Pa generator (it will naturally separate into two layers)

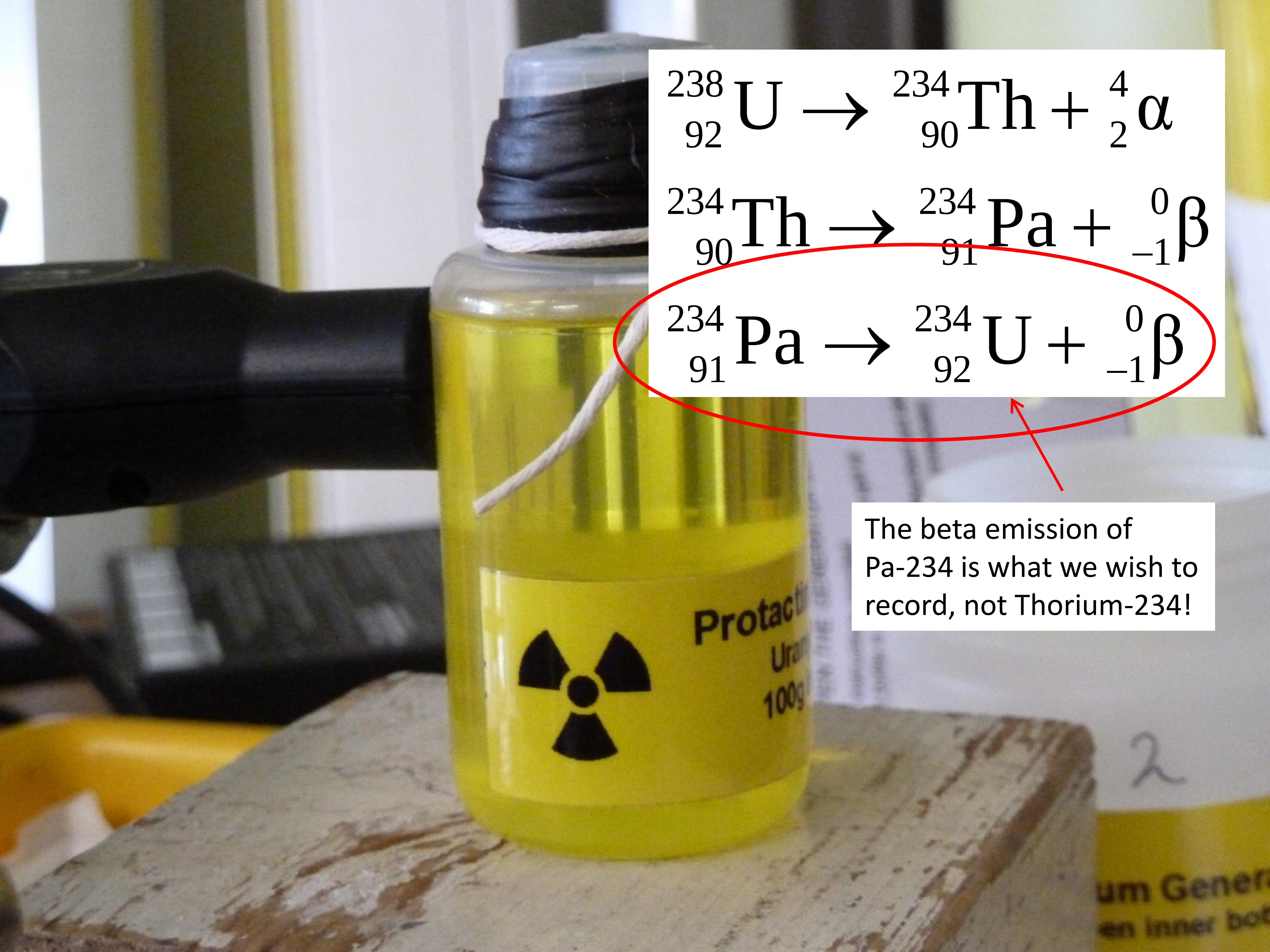
$$^{238}_{92}U \rightarrow\ ^{234}_{90}Th +\ ^{4}_{2}\alpha$$

$$^{234}_{90}Th \rightarrow\ ^{234}_{91}Pa +\ ^{0}_{-1}\beta$$

$$^{234}_{91}Pa \rightarrow\ ^{234}_{92}U +\ ^{0}_{-1}\beta$$

If you don't point the GM tube horizontally you may detect some of the other radiation from the Uranium or Thorium atoms in the mixture.





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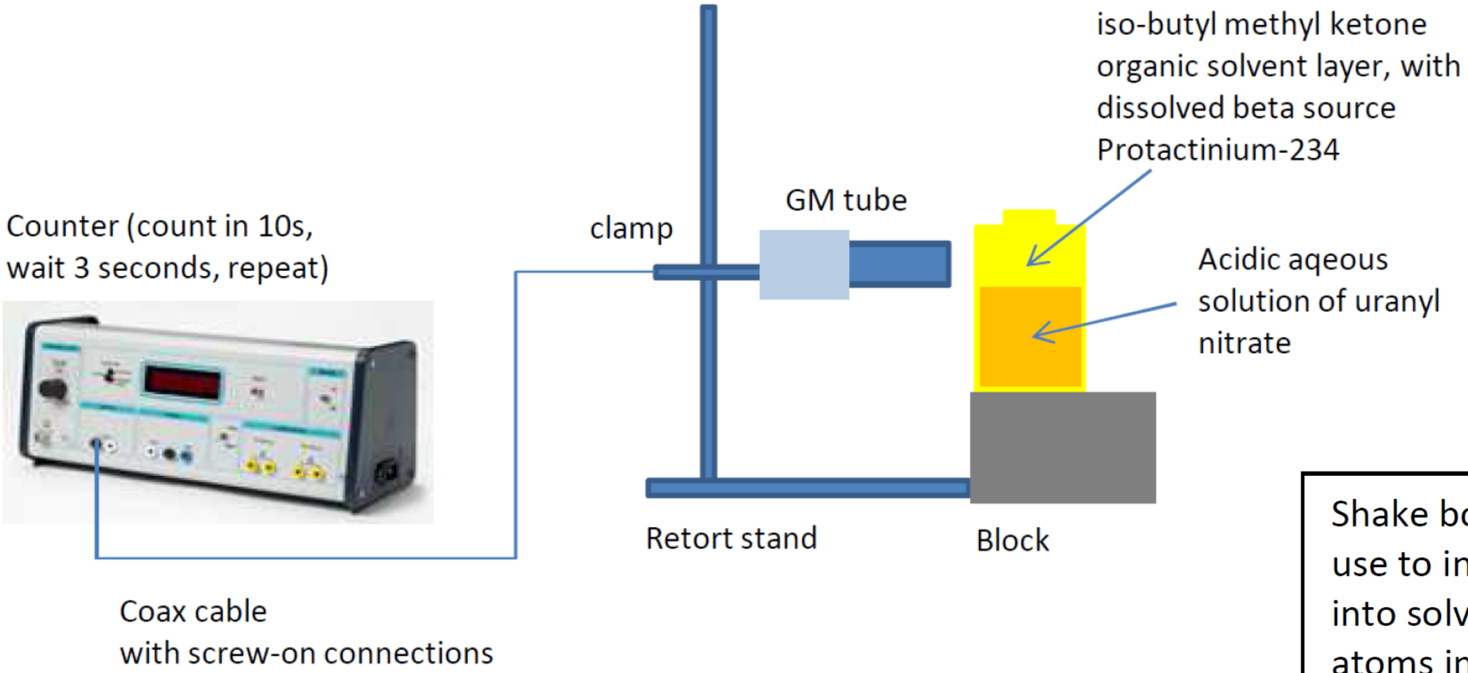
The beta emission of Pa-234 is what we wish to record, not Thorium-234!



Shake bottle before use to introduce Protactinium into solvent layer. The other atoms in the decay chain are not soluble in this layer.

* Shake Pa generator and start recording counts (a printed table or directly into a spreadsheet) per 10s every ten seconds.

* The counter will display the results for three seconds before starting to count again.

Collect experimental data

time/s	time/min	Count/10s	Count rate (sans background) (counts per second)	ln of count rate *
0	0.00			
13	0.22			
26	0.43			
39	0.65			
52	0.87			
65	1.08			
78	1.30			
91	1.52			
104	1.73			
117	1.95			
130	2.17			
143	2.38			
156	2.60			
169	2.82			
182	3.03			
195	3.25			
208	3.47			
221	3.68			
234	3.90			
247	4.12			
260	4.33			
273	4.55			
286	4.77			
299	4.98			
312	5.20			
325	5.42			
338	5.63			
351	5.85			
364	6.07			
377	6.28			
390	6.50			
403	6.72			
416	6.93			

* ln means Natural Logarithm. Use the ln button on your calculator.

BACKGROUND COUNT (100s) : ....

BACKGROUND COUNT RATE : ....

Data collection – *it is every 13 seconds,* so prepare a table in advance!

Work out the background level *after* you have finished the experiment i.e. what the asymptotic counts per 10s is after 416s.

Note the Pa generator will contribute to the background so better to use this *in situ* rather than measure a background *without* the Pa generator.

Alternatively measure the background level *before* you shake the Pa generator.

Protactinium-234 decays via beta emission. Compared to the other isotopes in the decay chain it has a very short (and therefore easily measurable) half life.

$$^{238}_{92}U \rightarrow\ ^{234}_{90}Th +\ ^{4}_{2}\alpha$$

$$^{234}_{90}Th \rightarrow\ ^{234}_{91}Pa +\ ^{0}_{-1}\beta$$

$$^{234}_{91}Pa \rightarrow\ ^{234}_{92}U +\ ^{0}_{-1}\beta$$

Isotope	**Half-life**
$^{238}_{92}U$	4.5 billion years
$^{234}_{90}Th$	24 days
$^{234}_{92}U$	246,000 years

A model of count-rate is *exponential decay* with time

$$\frac{dN}{dt} = \left.\frac{dN}{dt}\right|_{t=0} e^{-\lambda t}$$

$$\frac{dN}{dt} \Big/ \left.\frac{dN}{dt}\right|_{t=0} = \tfrac{1}{2}$$

$$\Rightarrow \exp\left(-\lambda T_{\frac{1}{2}}\right) = \tfrac{1}{2}$$

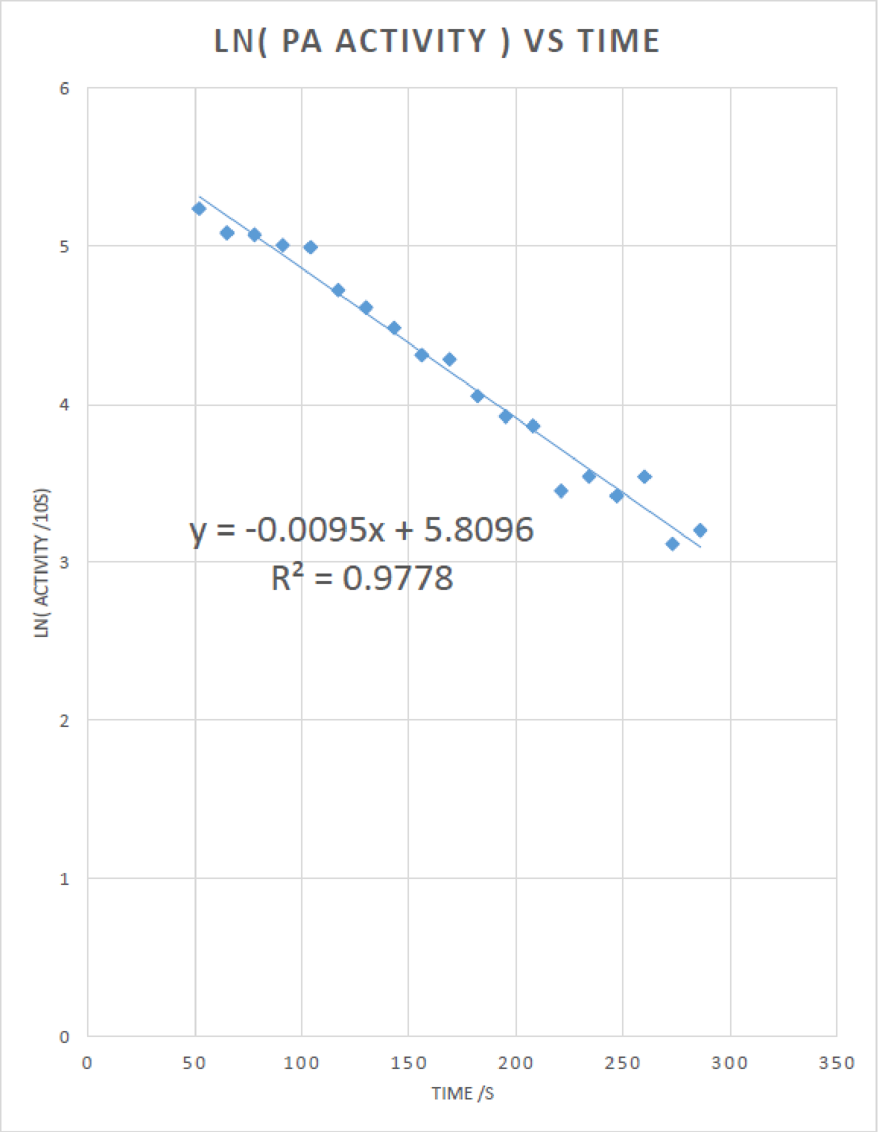
$$\therefore T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

Calculate *half-life* from the gradient of (t, ln(count-rate)) graph

→

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

$$\ln\left(\frac{dN}{dt}\right) = \ln\left(\left.\frac{dN}{dt}\right|_{t=0}\right) - \lambda t$$



$$A = -\frac{dN}{dt} = \lambda N \quad \therefore A = A_0 e^{-\lambda t}$$

$$\lambda = \frac{\ln 2}{t_{1/2}} \quad \therefore A = A_0 e^{-\frac{\ln 2}{t_{1/2}} t} \quad \therefore A = A_0 \left(e^{\ln 2}\right)^{-\frac{t}{t_{1/2}}}$$

$$\therefore A = \frac{A_0}{2^{\frac{t}{t_{1/2}}}}$$

$$b = a^{\log_a b}$$

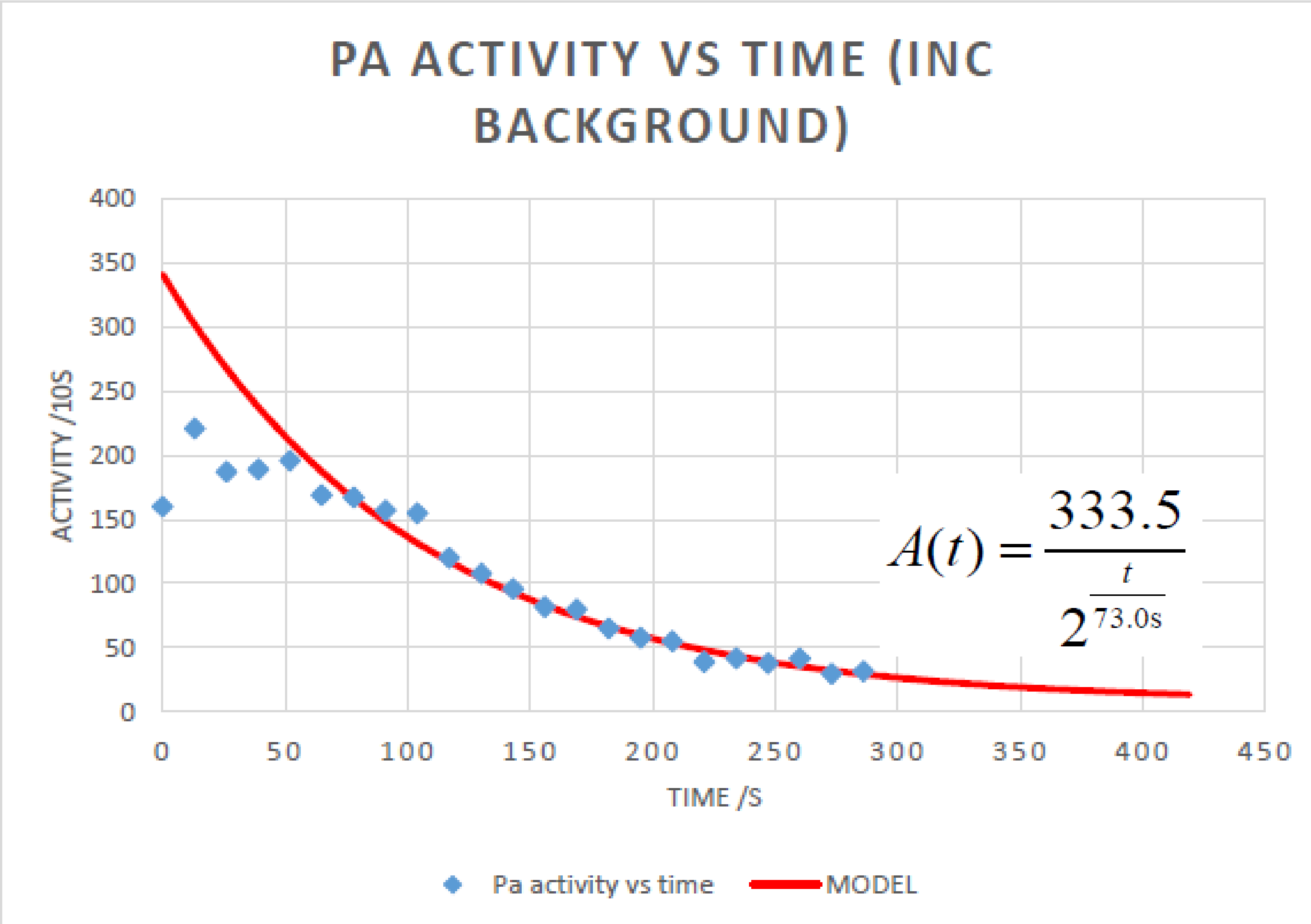
$$A = \frac{A_0}{2^{\frac{t}{t_{1/2}}}} \quad \therefore \ln A = \ln A_0 - \frac{t}{t_{1/2}} \ln 2$$

$$\frac{\ln 2}{t_{1/2}} = 0.0095 \quad \therefore t_{1/2} = \frac{\ln 2}{0.0095} = 73.0\text{s}$$

$$\ln A_0 = 5.8096 \quad \therefore A_0 = e^{5.8096} = 333.5$$

$$\therefore A(t) = \frac{333.5}{2^{\frac{t}{73.0\text{s}}}}$$

Find the half life from the gradient of ln A vs t graph.



In this experiment an initial activity of about 334Bq decays by a factor of two every 73s.

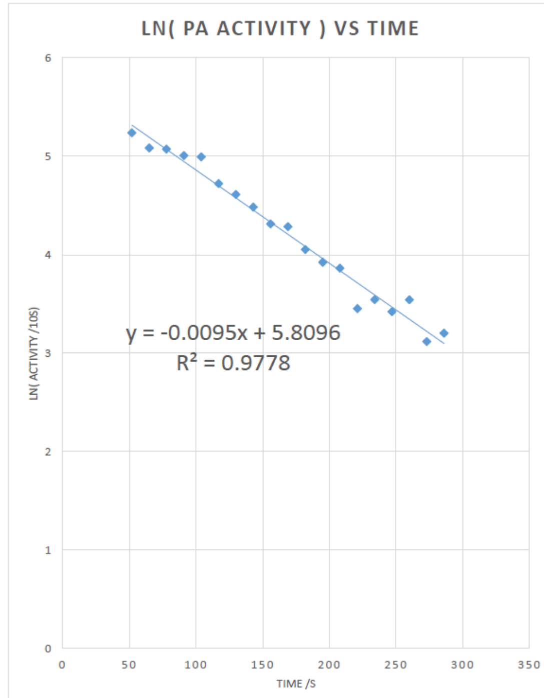
In this case, estimate the half life to be about 73.0s. About 70+/-5 seconds is reasonable.

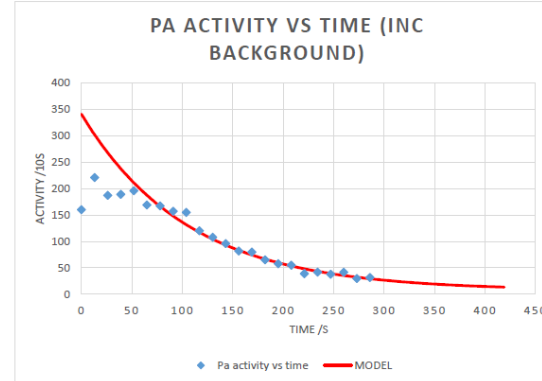
HALF LIFE OF PROTACTINIUM

17/03/2020

BACKGROUND (/10s) 7.4

Count rate /10s	t /s	A Count rate /10s - background	ln(A)
160	0	152.6	5.03
221	13	213.6	5.36
187	26	179.6	5.19
189	39	181.6	5.2
196	52	188.6	5.24
169	65	161.6	5.09
167	78	159.6	5.07
157	91	149.6	5.01
155	104	147.6	4.99
120	117	112.6	4.72
108	130	100.6	4.61
96	143	88.6	4.48
82	156	74.6	4.31
80	169	72.6	4.28
65	182	57.6	4.05
58	195	50.6	3.92
55	208	47.6	3.86
39	221	31.6	3.45
42	234	34.6	3.54
38	247	30.6	3.42
42	260	34.6	3.54
30	273	22.6	3.12
32	286	24.6	3.2





$$A = \frac{A_0}{2^{\frac{t}{t_{1/2}}}} \quad \therefore \ln A = \ln A_0 - \frac{t}{t_{1/2}} \ln 2$$

$$\frac{\ln 2}{t_{1/2}} = 0.0095 \quad \therefore t_{1/2} = \frac{\ln 2}{0.0095} = 73.0\text{s}$$

$$\ln A_0 = 5.8096 \quad \therefore A_0 = e^{5.8096} = 333.5$$

$$\therefore A(t) = \frac{333.5}{2^{\frac{t}{73.0\text{s}}}}$$

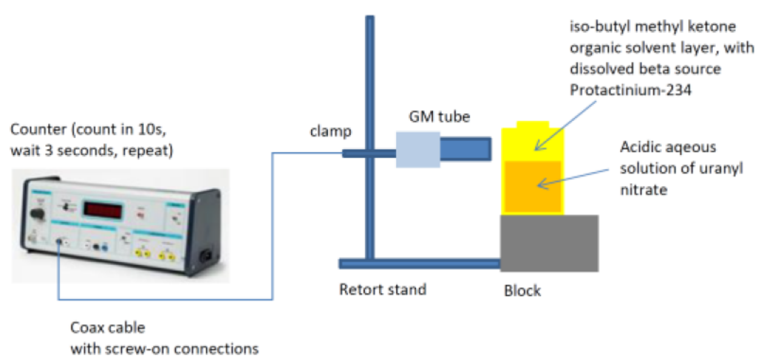
MODEL

t /s	A + background
0	341
1	338
2	335
3	332
4	328
5	325
6	322
7	319
8	317

$${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\alpha$$

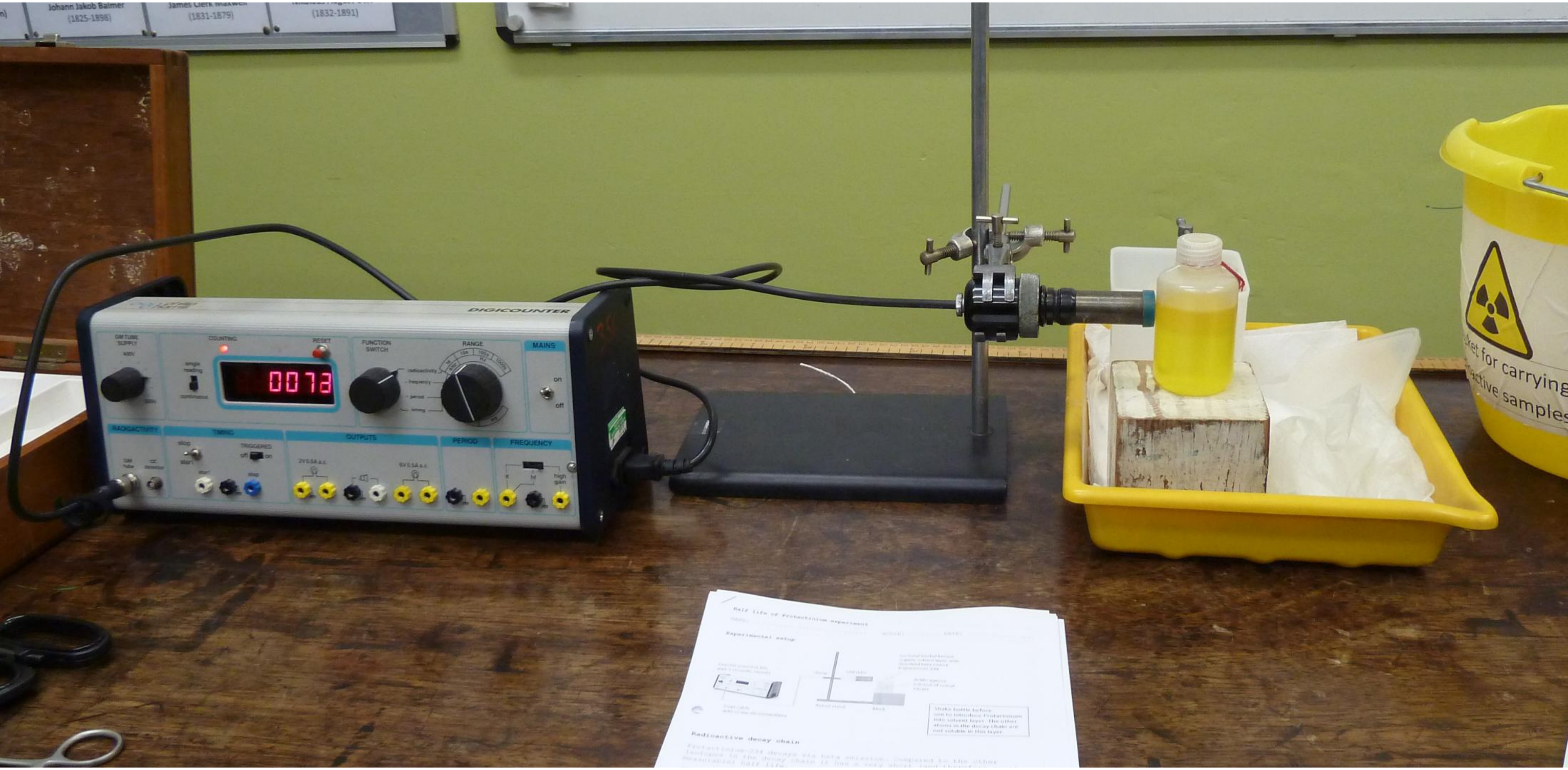
$${}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\beta$$

$${}^{234}_{91}\text{Pa} \rightarrow {}^{234}_{92}\text{U} + {}^{0}_{-1}\beta$$



Shake bottle before use to introduce Protactinium into solvent layer. The other atoms in the decay chain are not soluble in this layer.

Note Thorium-234 has a half life of 24 days. Uranium-238 and Uranium-234 have long half lives of 4.5 billion years and 246,000 years respectively, so their activity can be assumed to be constant!


Johann Jakob Balmer
(1825-1898)
James Clerk Maxwell
(1831-1879)
(1832-1891)
DIGICOUNTER
GM TUBE SUPPLY
COUNTING
RESET
0072
FUNCTION SWITCH
RANGE
MAINS
on
off
RADIOACTIVITY
TIMING
OUTPUTS
PERIOD
FREQUENCY
Half life of Protactinium experiment
Experimental setup
Radioactive decay chain
ket for carrying
ctive samples