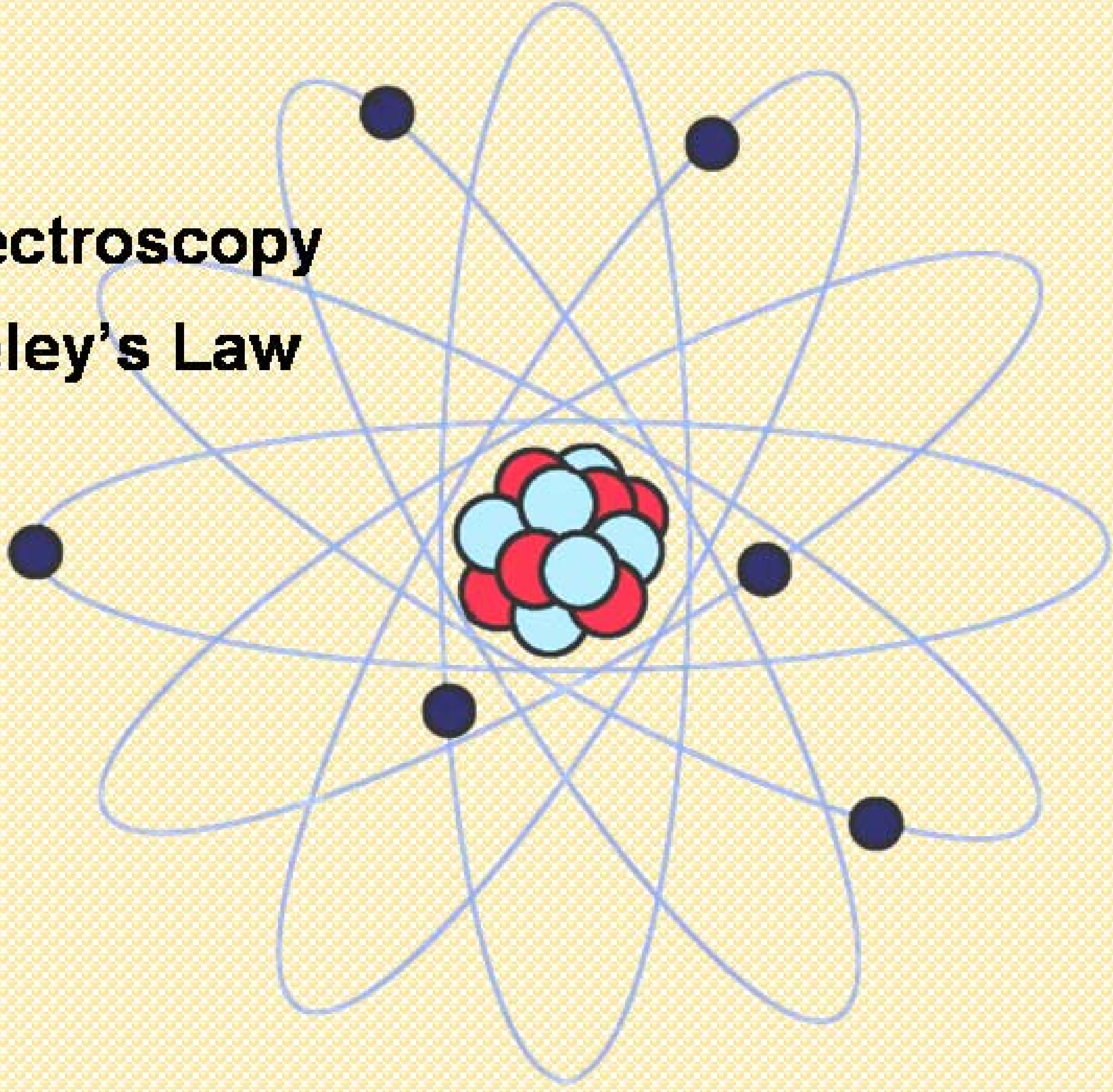
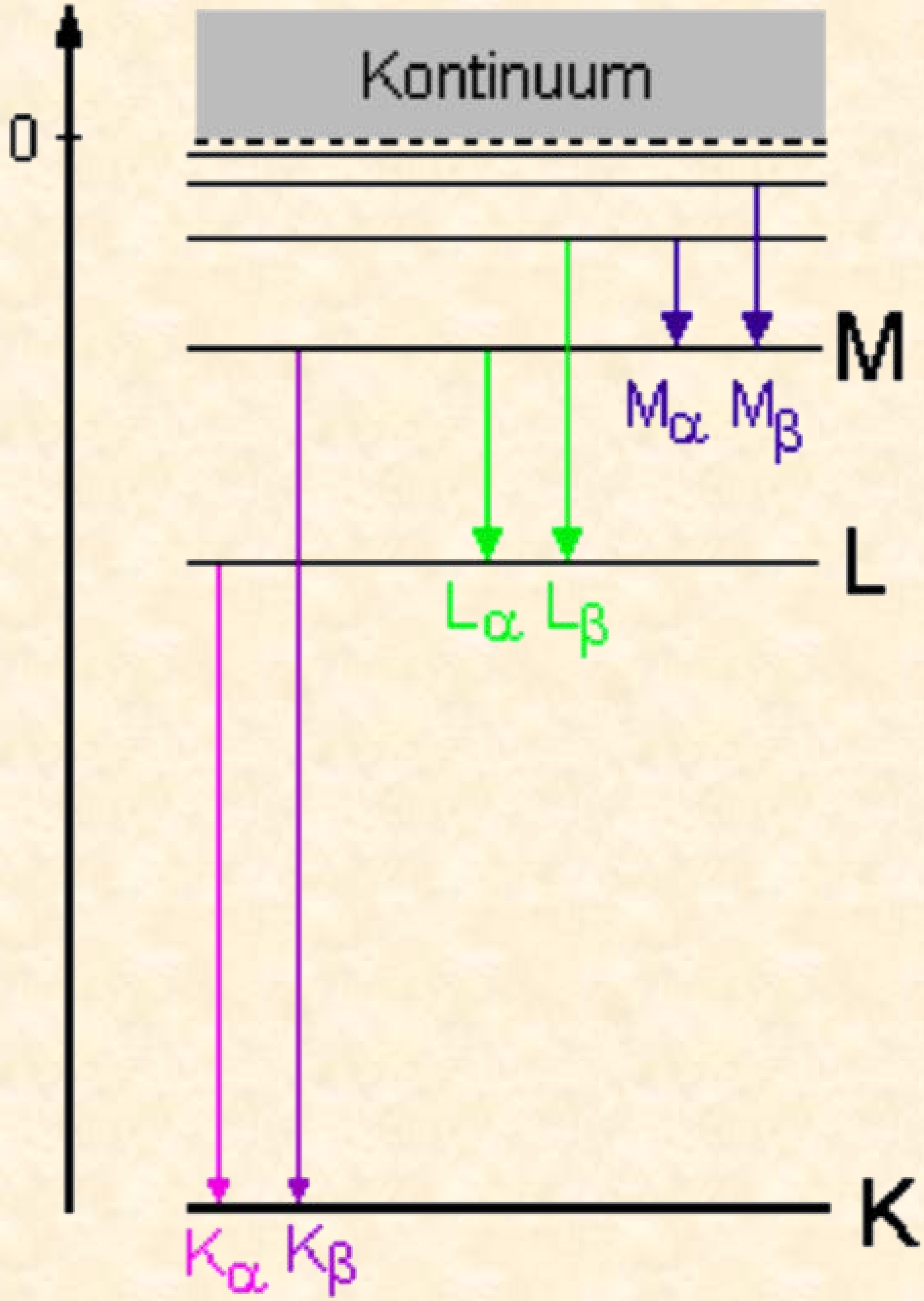
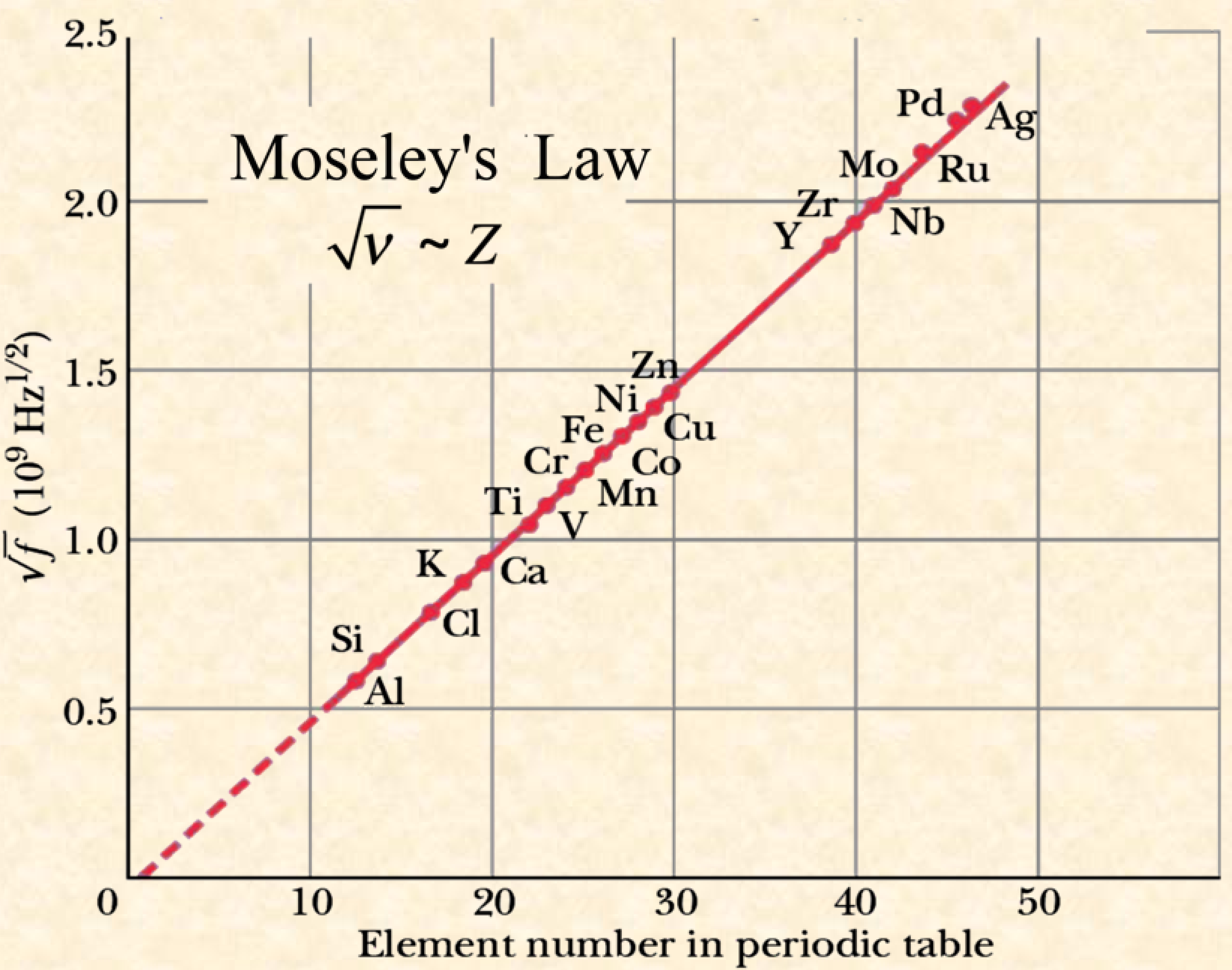
X-Ray Spectroscopy and Moseley's Law



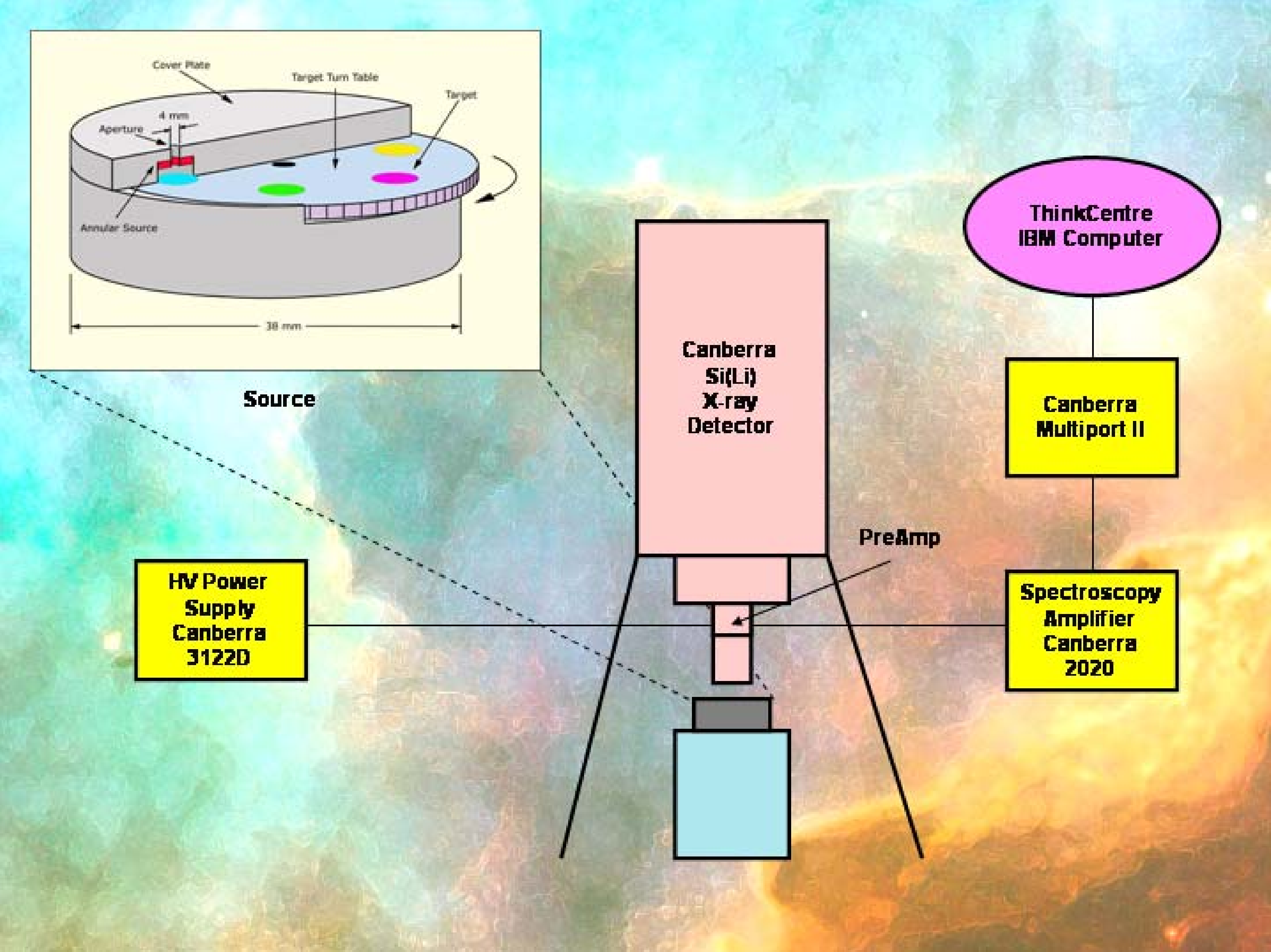

Henry Gwyn Jeffreys Moseley
1887 - 1915



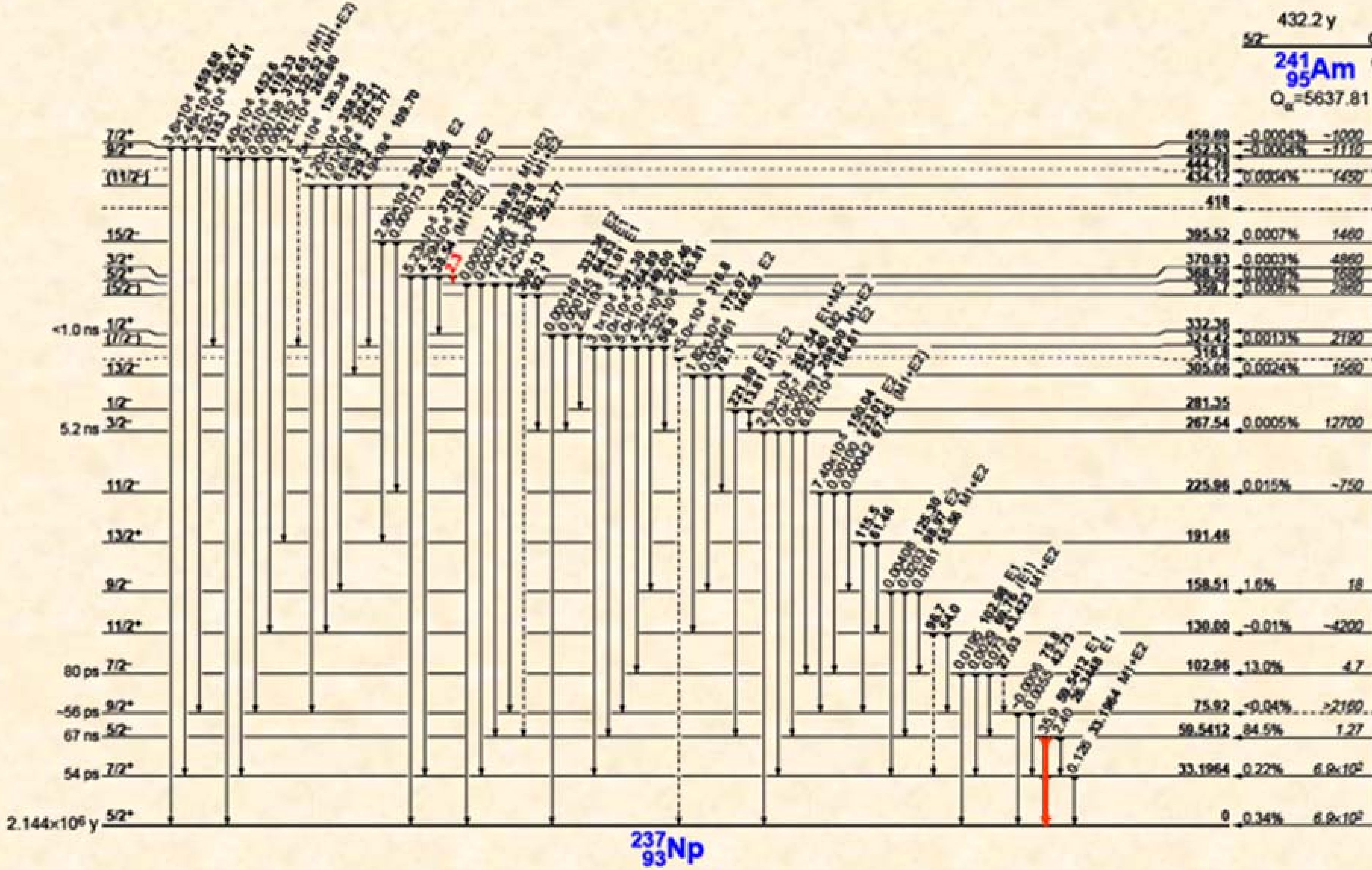
Kontinuum
0
M
Mα
Mβ
L
Lα
Lβ
K
Kα
Kβ

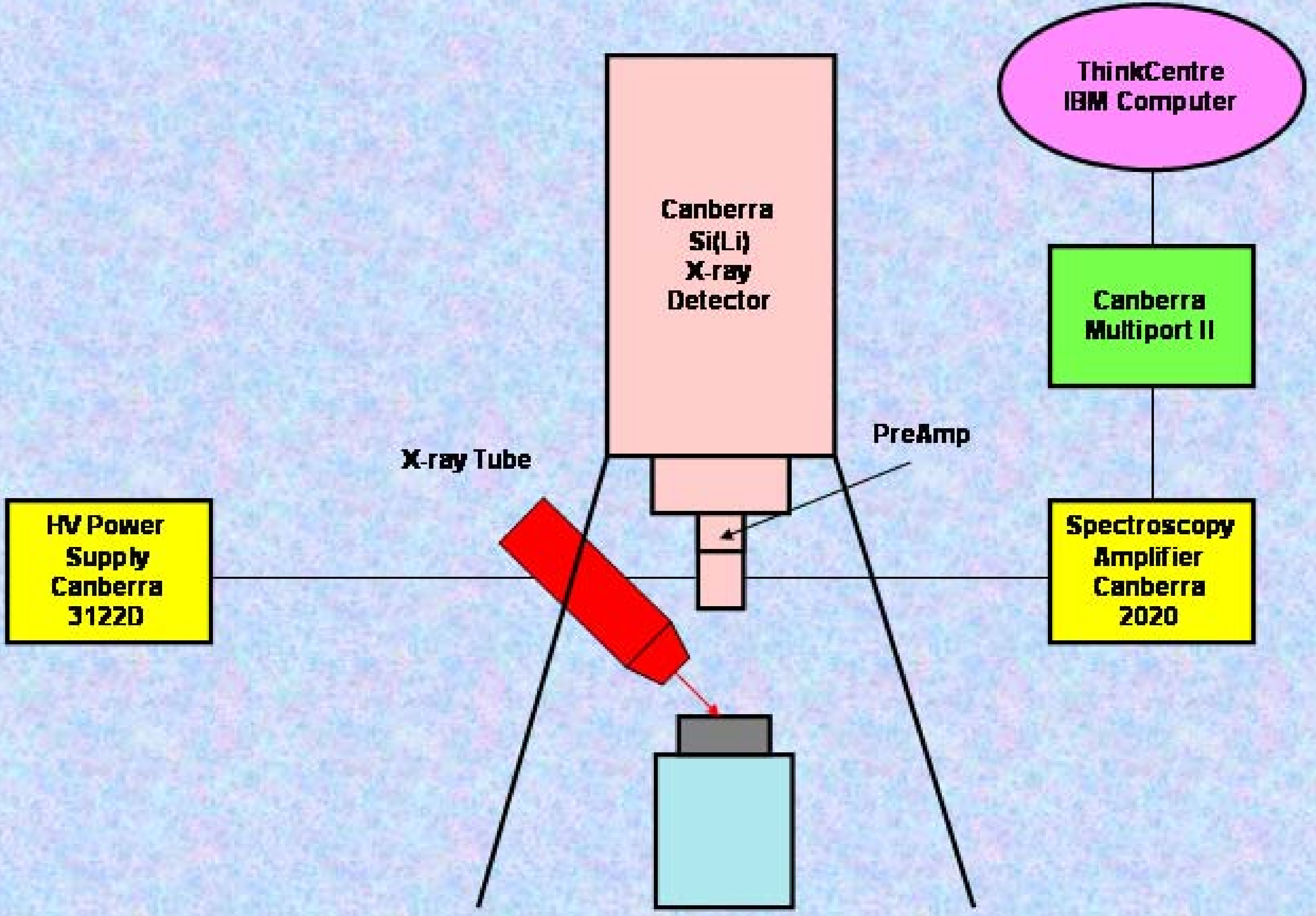

Moseley's Law
$\sqrt{\nu} \sim Z$
$\sqrt{f}$ (10^9 Hz$^{1/2}$)
2.5
2.0
1.5
1.0
0.5
0
10
20
30
40
50
Element number in periodic table
Al
Si
Cl
K
Ca
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Y
Zr
Nb
Mo
Ru
Pd
Ag

Material Analysis using X-Ray Fluorescence (XRFA)



Cover Plate
Target Turn Table
Target
4 mm
Aperture
Annular Source
38 mm
Source
Canberra Si(Li) X-ray Detector
ThinkCentre IBM Computer
Canberra Multiport II
PreAmp
HV Power Supply Canberra 3122D
Spectroscopy Amplifier Canberra 2020


432.2 y
5/2-
241 95 Am
Qα=5637.81
7/2+
9/2+
(11/2-)
15/2-
3/2+
5/2+
(5/2-)
<1.0 ns
1/2+
(7/2-)
13/2-
1/2-
5.2 ns
3/2-
11/2-
13/2+
9/2-
11/2+
80 ps
7/2-
~56 ps
9/2+
67 ns
5/2-
54 ps
7/2+
2.144×10⁶ y
5/2+
459.69
452.53
444.75
434.12
418
395.52
370.93
368.59
359.7
332.36
324.42
316.8
305.06
281.35
267.54
225.96
191.46
158.51
130.00
102.96
75.92
59.5412
33.1964
0
~0.0004%
~0.0004%
0.0004%
0.0007%
0.0003%
0.0013%
0.0024%
0.0005%
0.015%
1.6%
~0.01%
13.0%
<0.04%
84.5%
0.22%
0.34%
~1000
~1110
1450
1460
4860
2190
1580
12700
~750
18
~4200
4.7
>2160
1.27
6.9×10³
6.9×10³
237 93 Np


ThinkCentre
IBM Computer
Canberra
Si(Li)
X-ray
Detector
Canberra
Multiport II
PreAmp
X-ray Tube
HV Power
Supply
Canberra
3122D
Spectroscopy
Amplifier
Canberra
2020

ECLIPSE IV
X-ray tube
AmpTek and Oxford Instr.

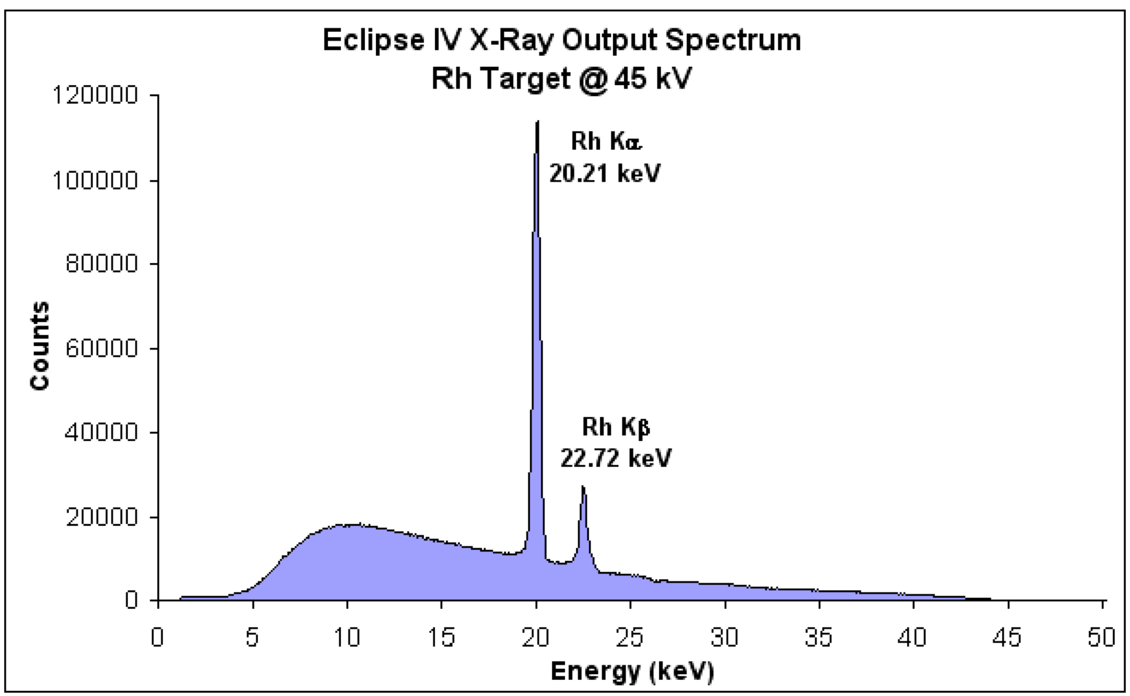
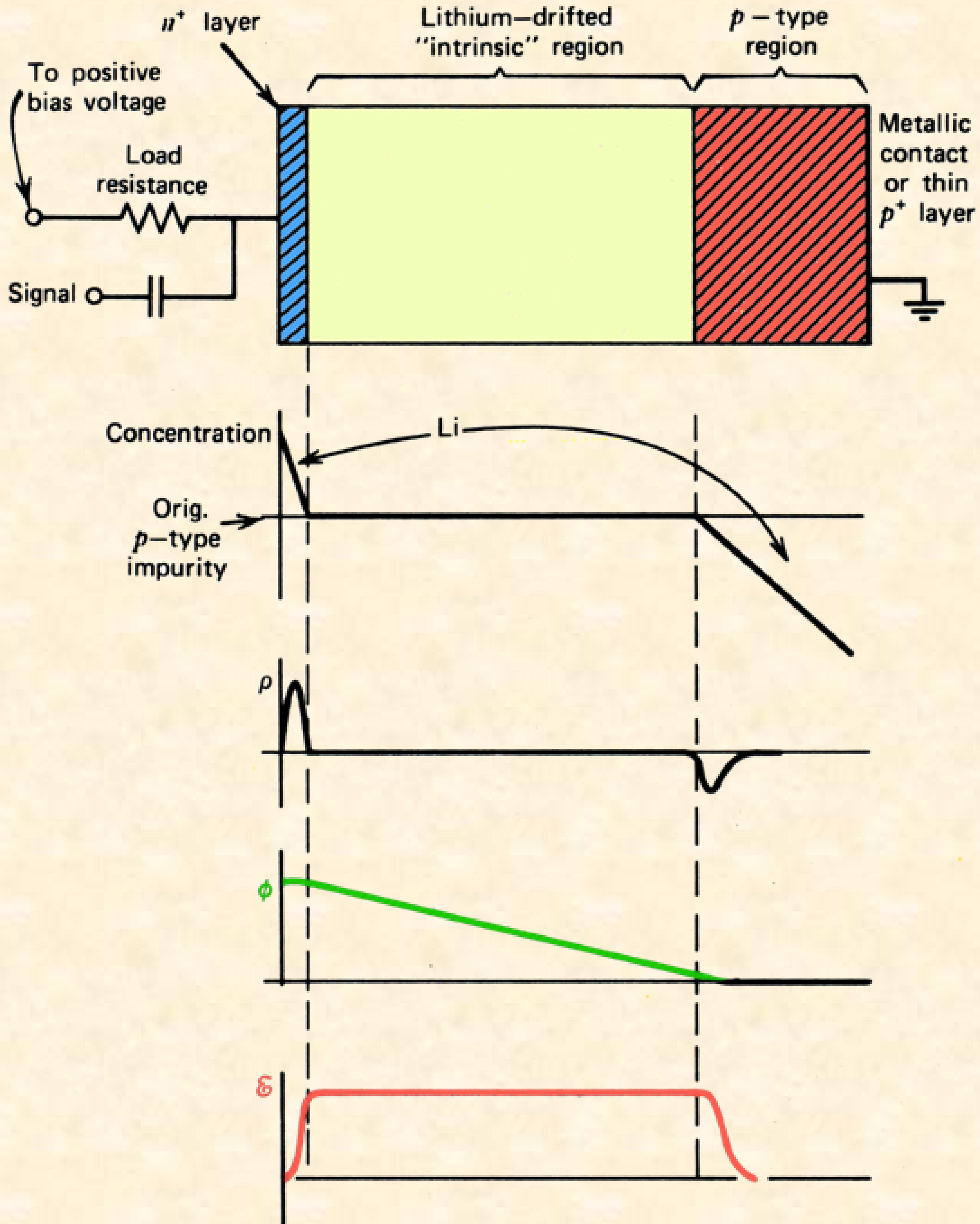
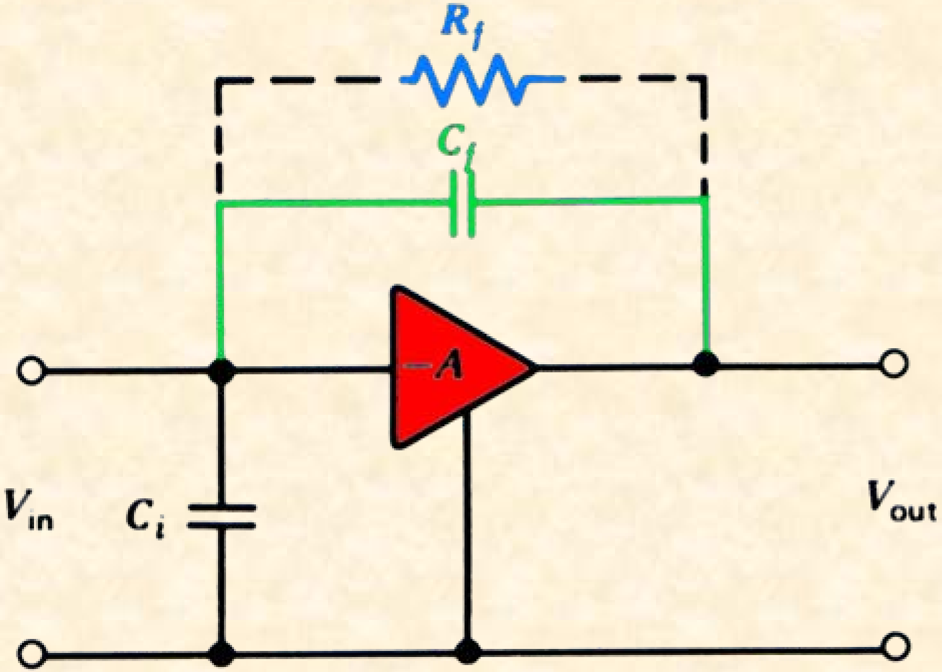


Figure 1. Eclipse-IV output spectrum at 45 kV.



n^+ layer
Lithium–drifted "intrinsic" region
p – type region
To positive bias voltage
Load resistance
Signal
Metallic contact or thin p^+ layer
Concentration
Li
Orig. p–type impurity
ρ
ϕ
$\mathcal{E}$

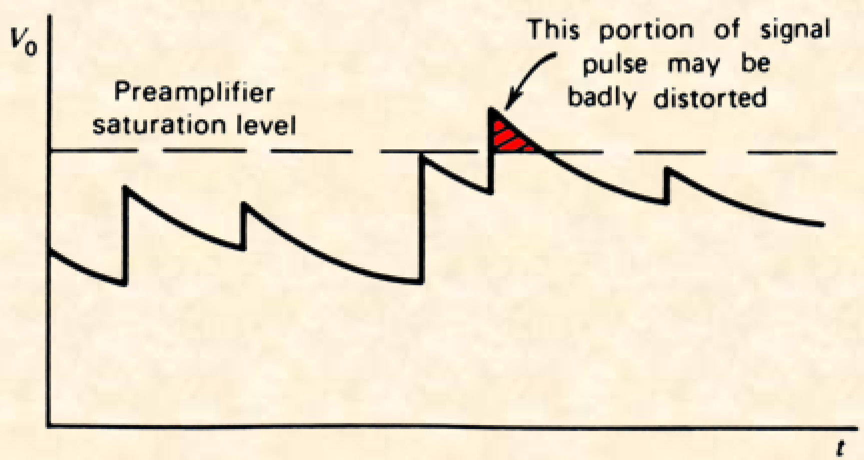


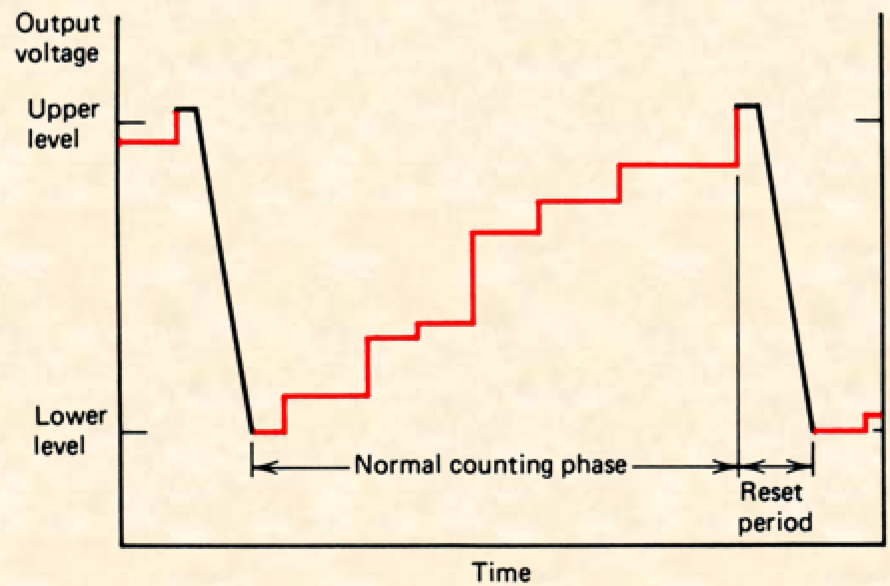
Assume $A >> (C_i + C_f)/C_f$

$$V_{out} = -A\, V_{in}$$

$$V_{out} = -A \frac{Q}{C_i + (A+1)C_f}$$

$$V_{out} \cong -\frac{Q}{C_f}$$





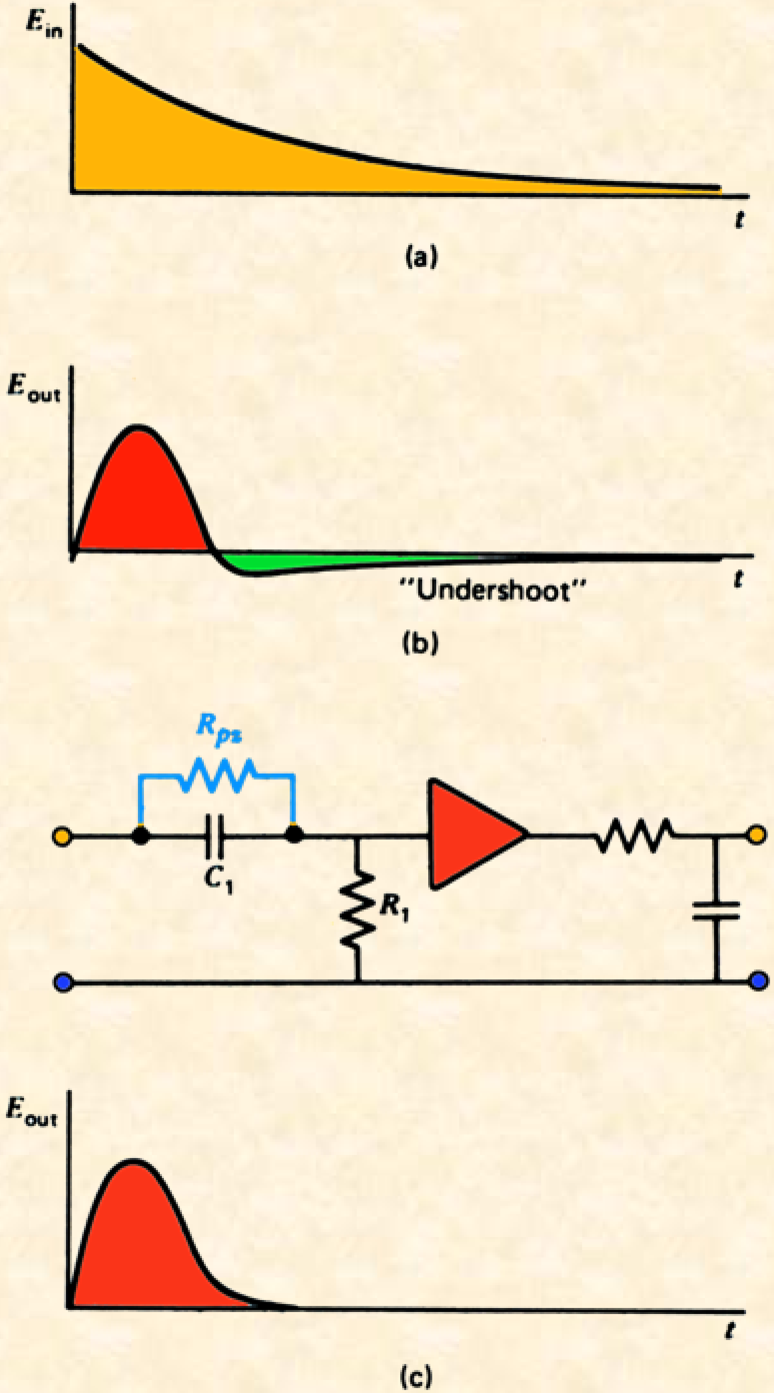
- A detector is a kind of transducer, a physical entity is coded as an electronic signal

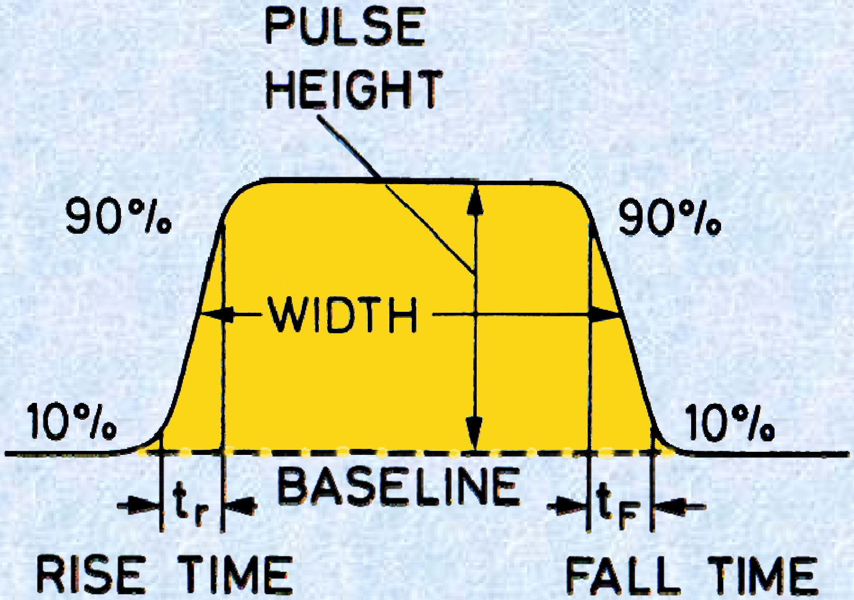
- Linear relation between X-ray energy and output pulse amplitude

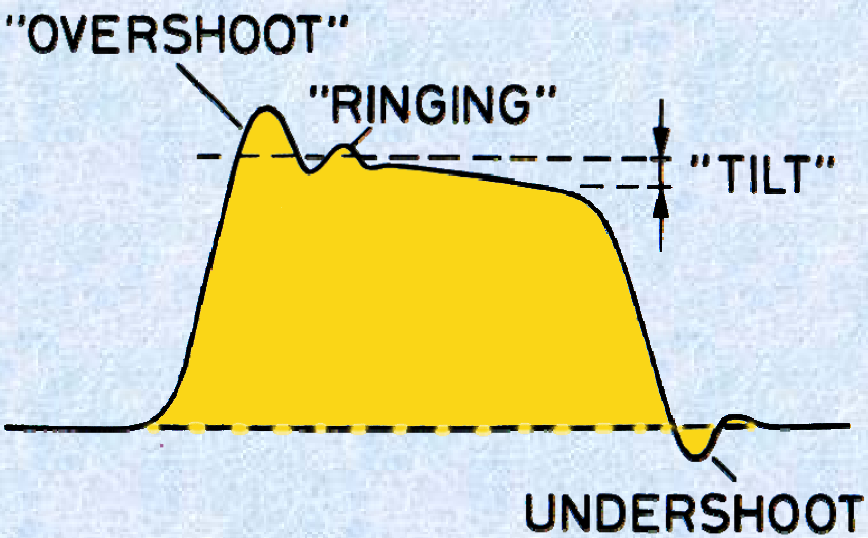
- We are measuring voltages, dynamic range 0 – 8V in ~ 1 microsec; resolution several millivolts

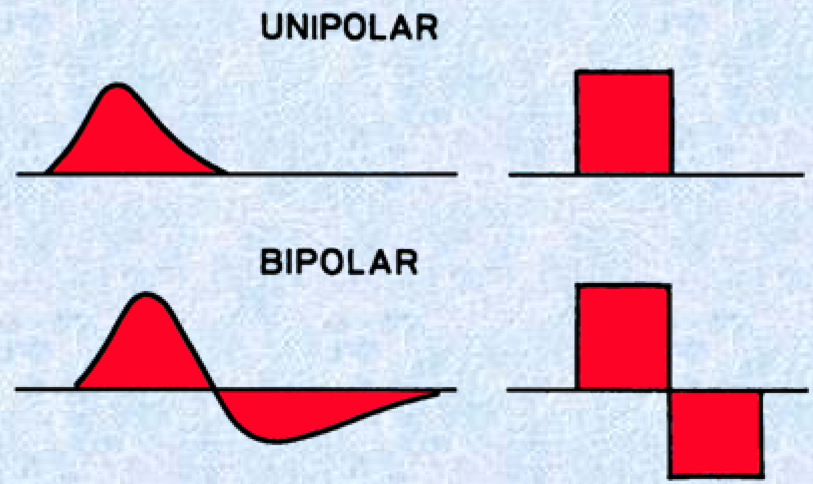
- We have to understand the information chain, we need clear and clean conditions

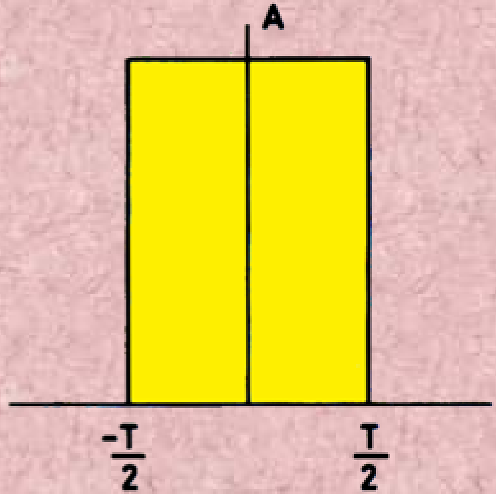
Pole Zero Cancellation

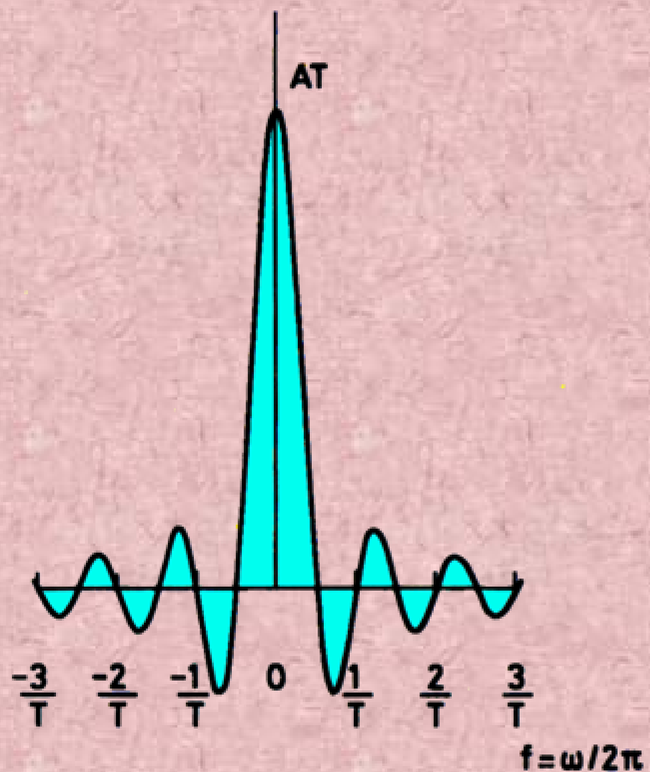


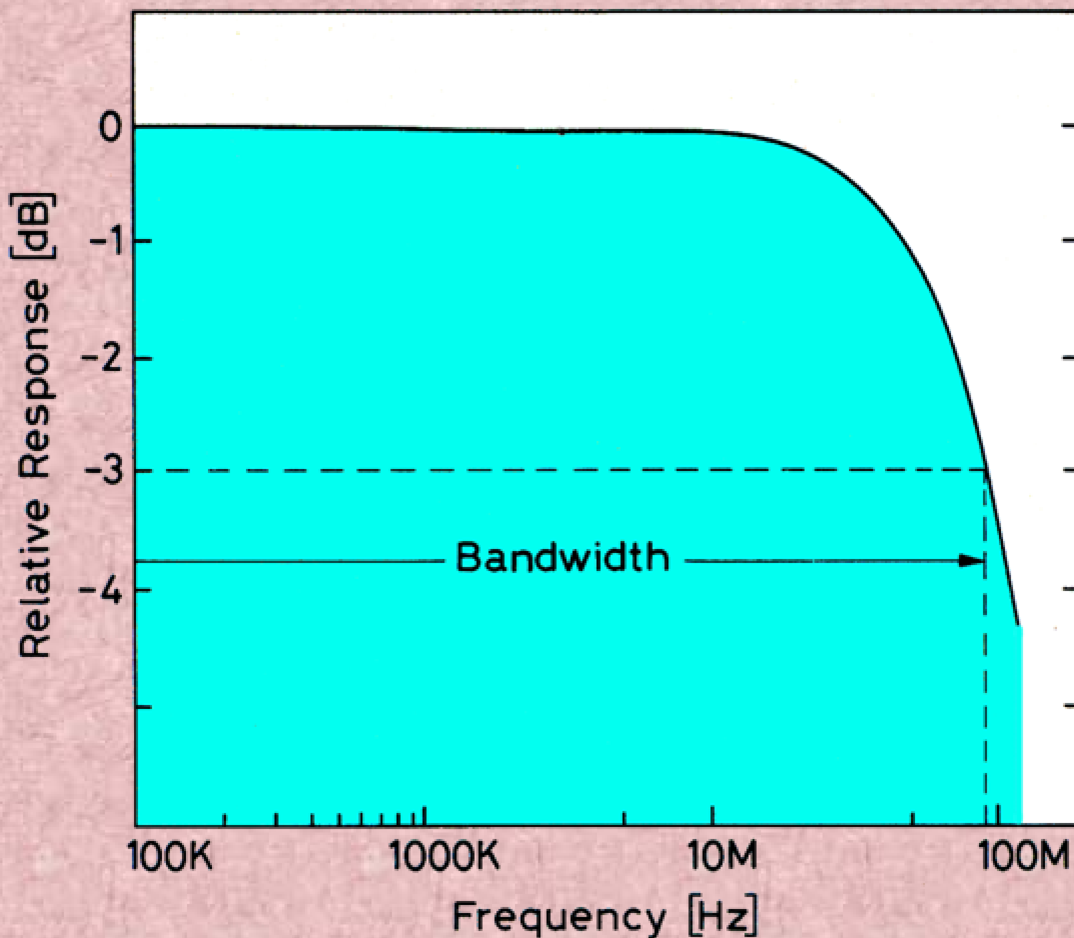

PULSE
HEIGHT
90%
90%
WIDTH
10%
10%
BASELINE
t_r
t_F
RISE TIME
FALL TIME

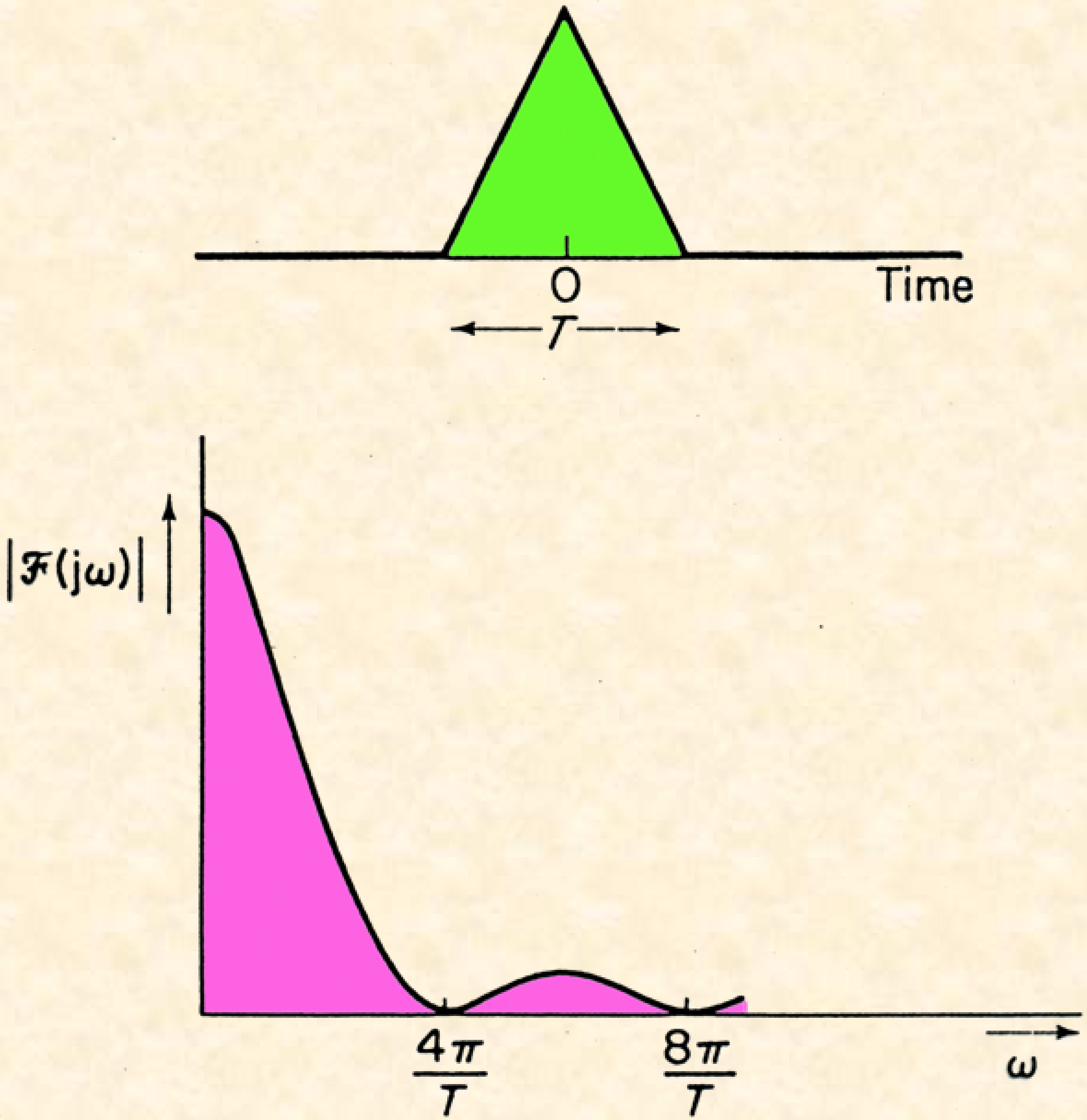

"OVERSHOOT"
"RINGING"
"TILT"
UNDERSHOOT


UNIPOLAR
BIPOLAR

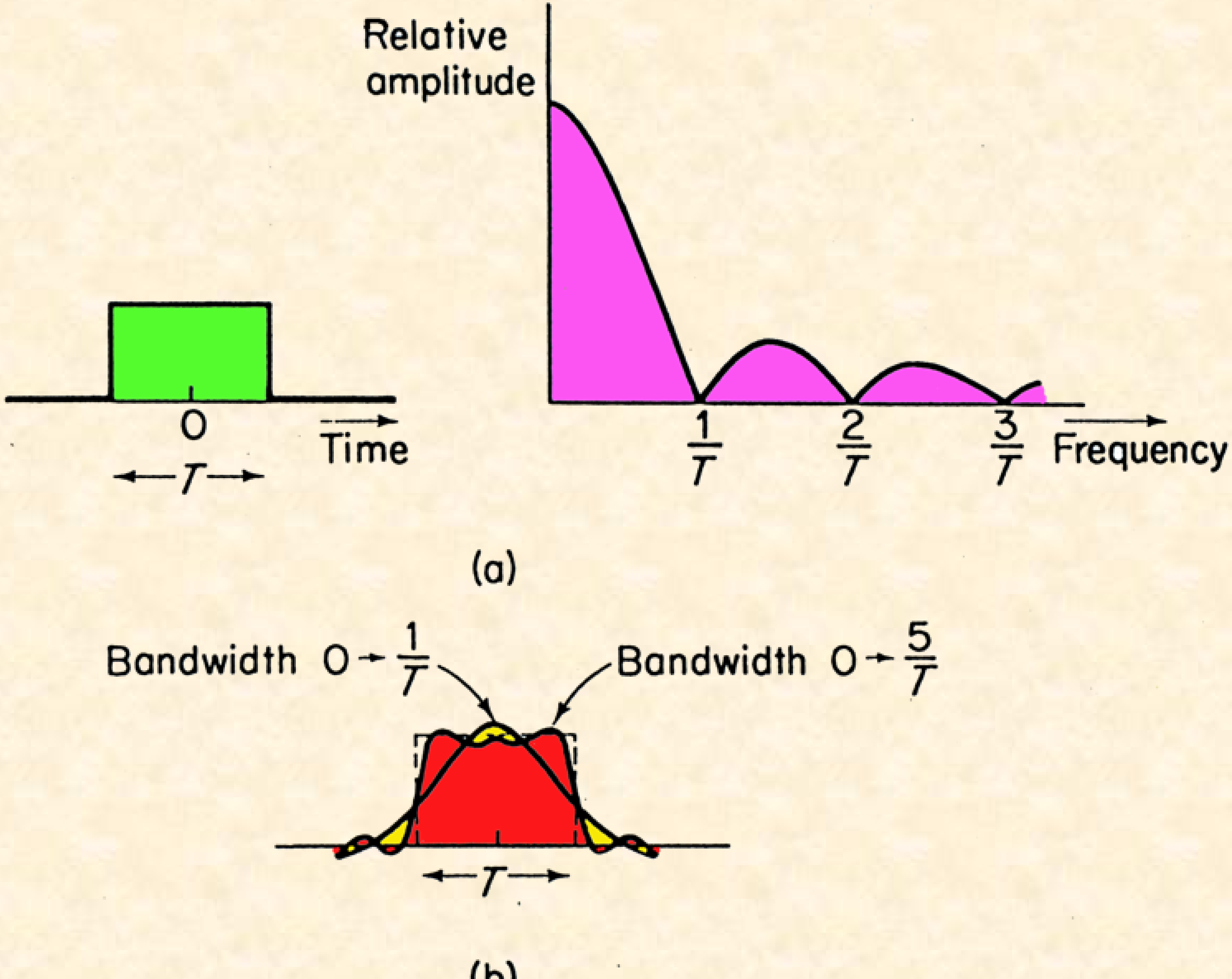

A
-T/2
T/2


AT
-3/T
-2/T
-1/T
0
1/T
2/T
3/T
f=ω/2π

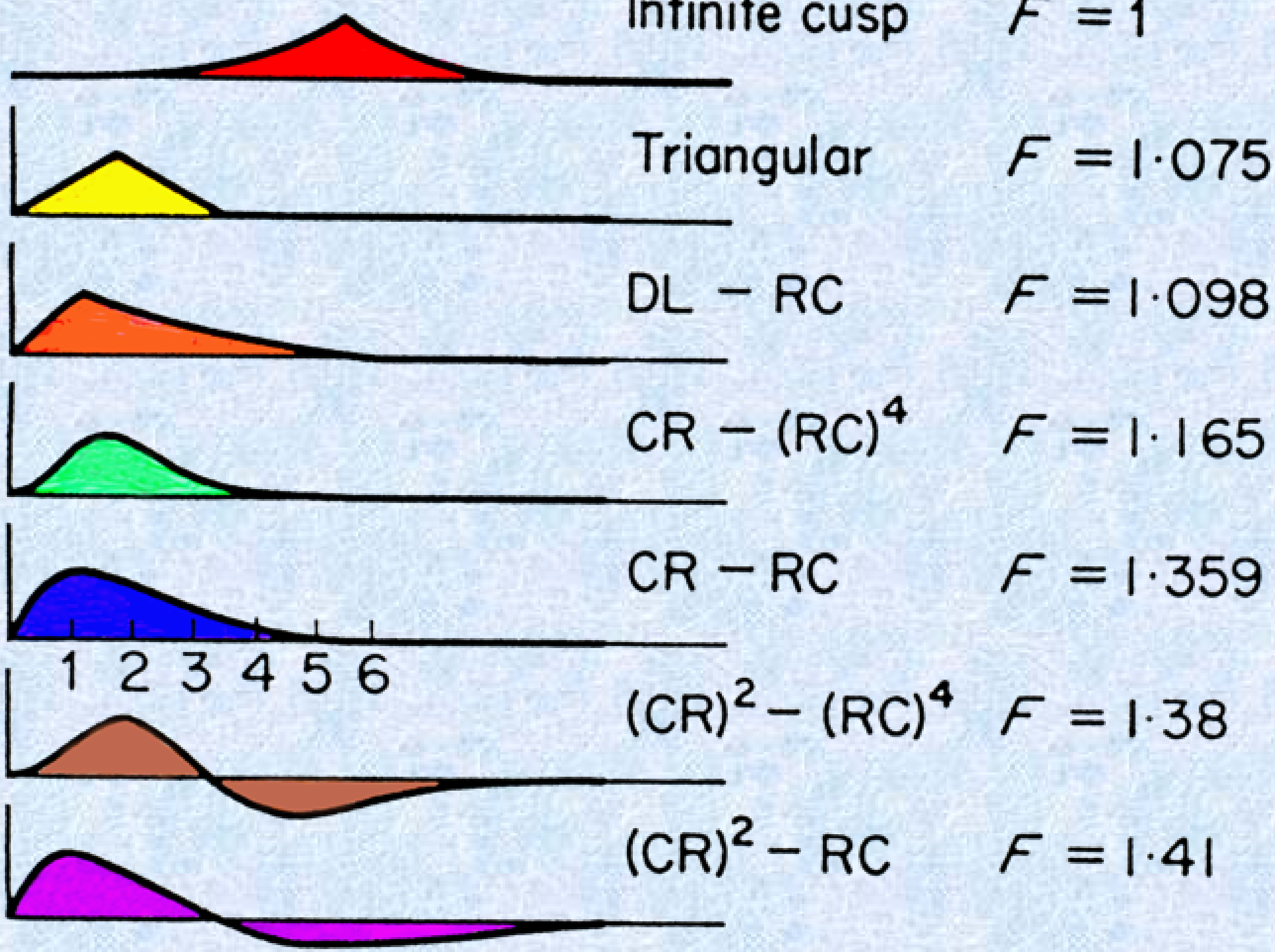

0
-1
-2
-3
-4
Relative Response [dB]
Bandwidth
100K
1000K
10M
100M
Frequency [Hz]



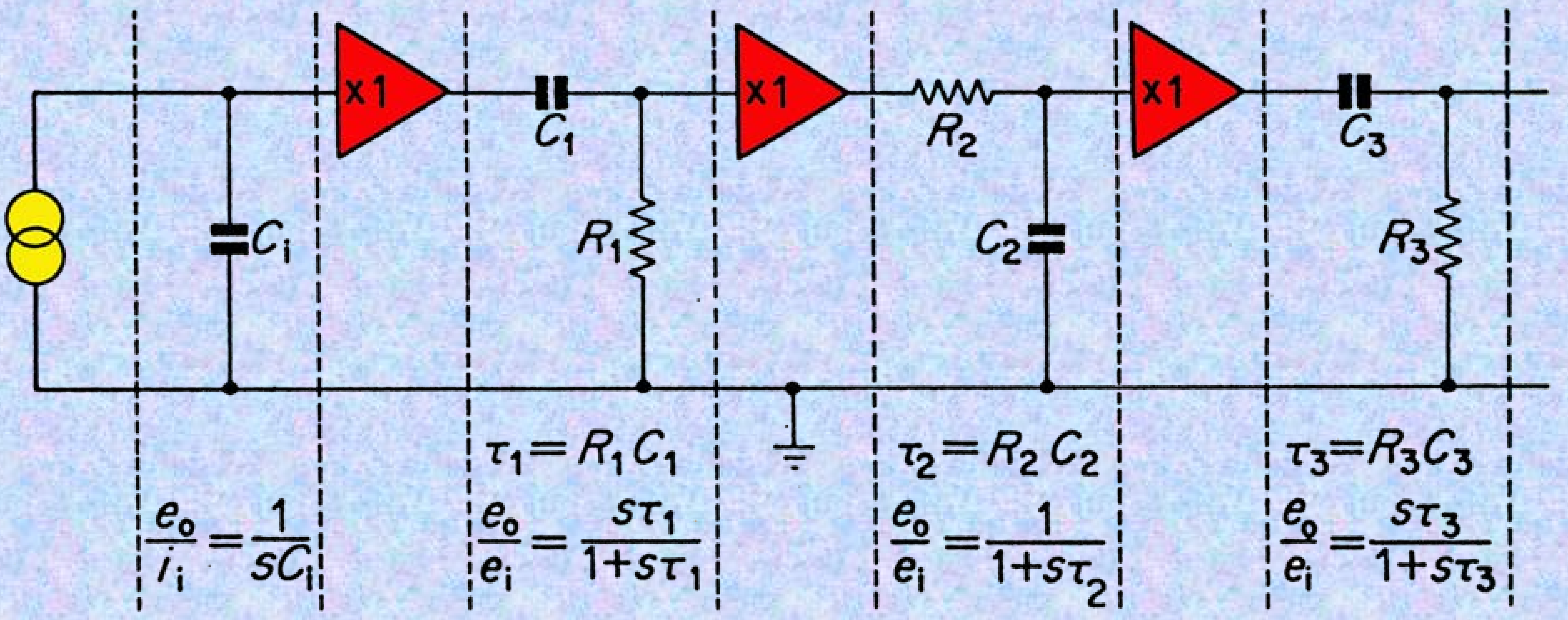
Triangular pulse and its frequency (Fourier) spectrum



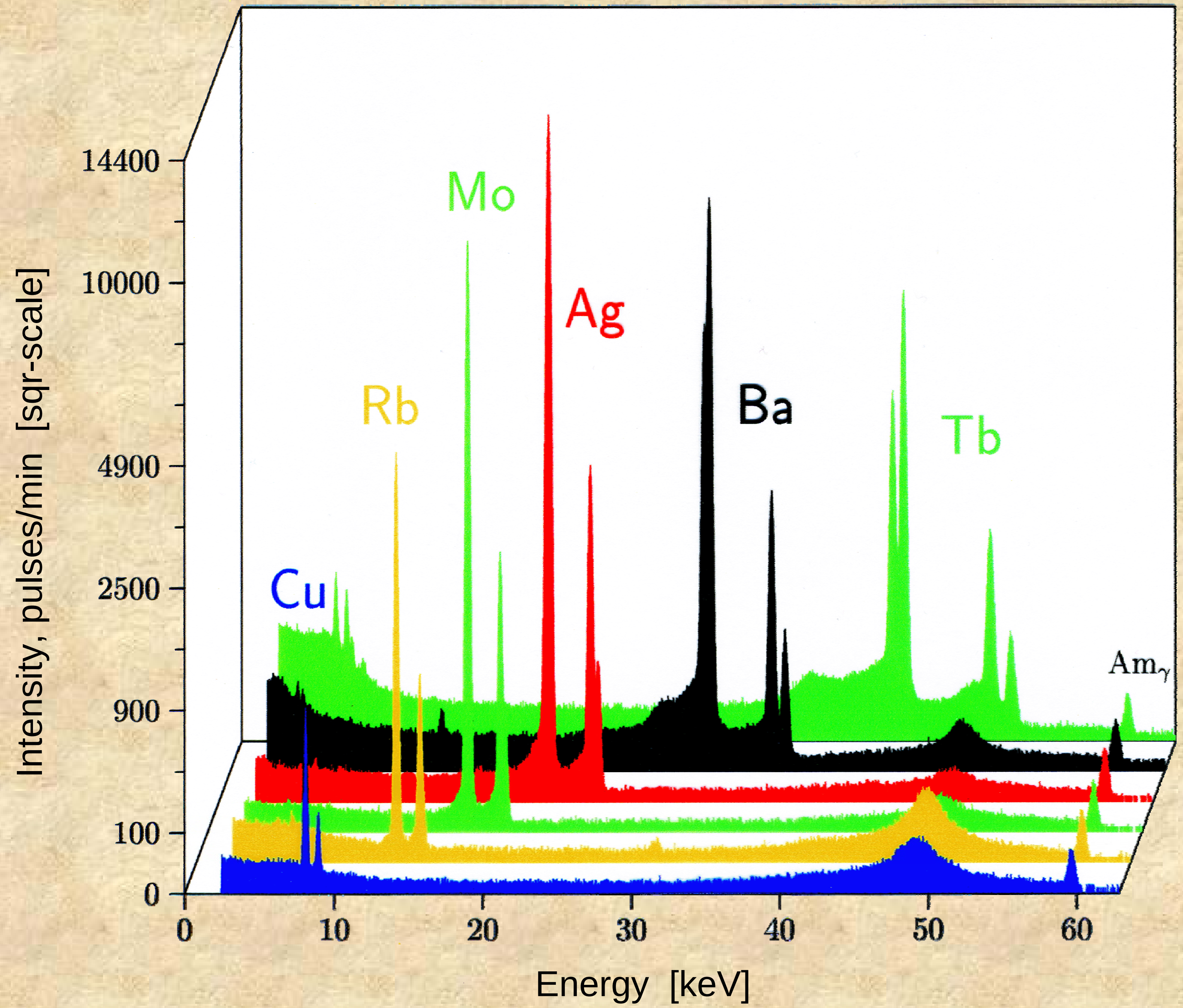
(a) Frequency (Fourier) spectrum of a rectangular pulse of duration T. (b) Effect on the pulse shape of the removal of all frequencies above $1/T$ and above $5/T$



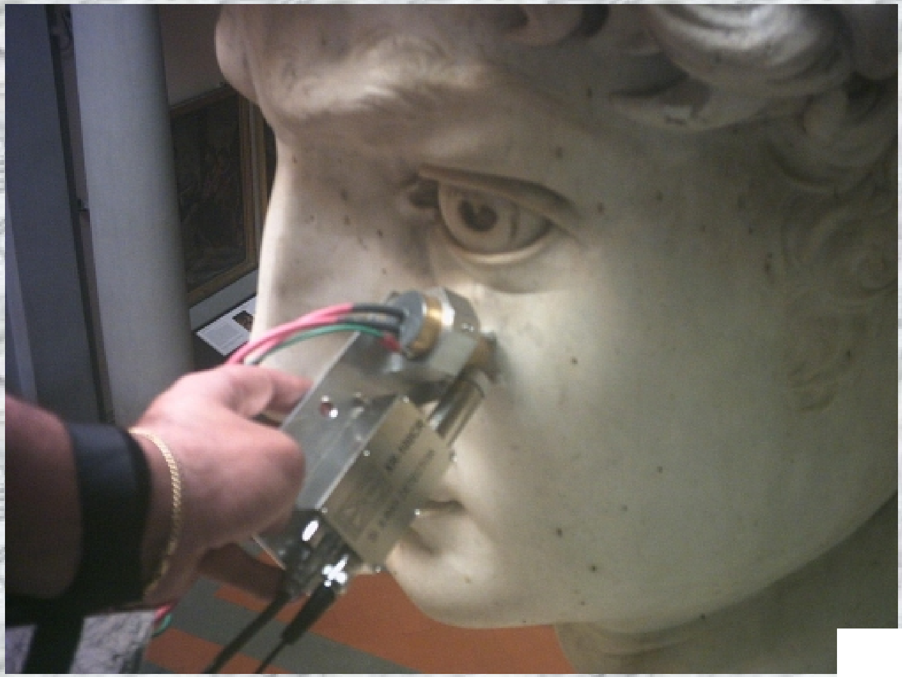
Pulse shapes, normalized to constant height, for various systems when the time scale of each (i.c. the value of τ) is optimized for the case of a noise corner time τ_c equal to 1. The curves shown are adapted from those given by Konrad[20]



Equivalent circuit for $(CR)^2$-RC shaping

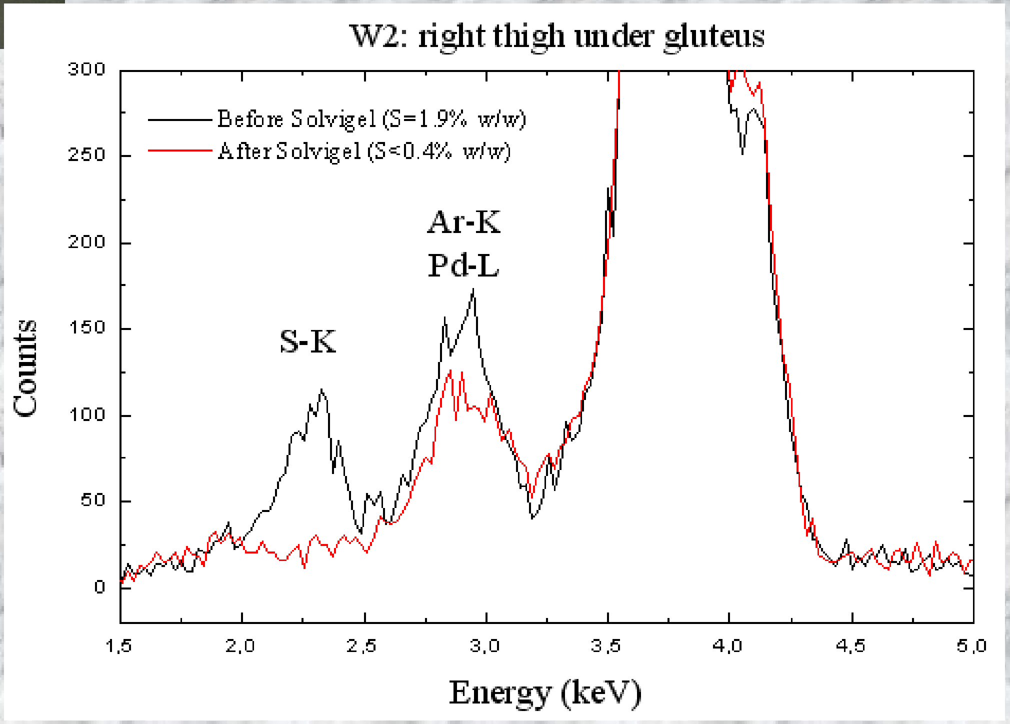

Intensity, pulses/min [sqr-scale]
14400
10000
4900
2500
900
100
0
Energy [keV]
0
10
20
30
40
50
60
Cu
Rb
Mo
Ag
Ba
Tb
Am_γ

The Restoration of Michelangelo's David



Taking an x-ray fluorescence spectrum of David

Typical spectrum before and after cleaning treatment

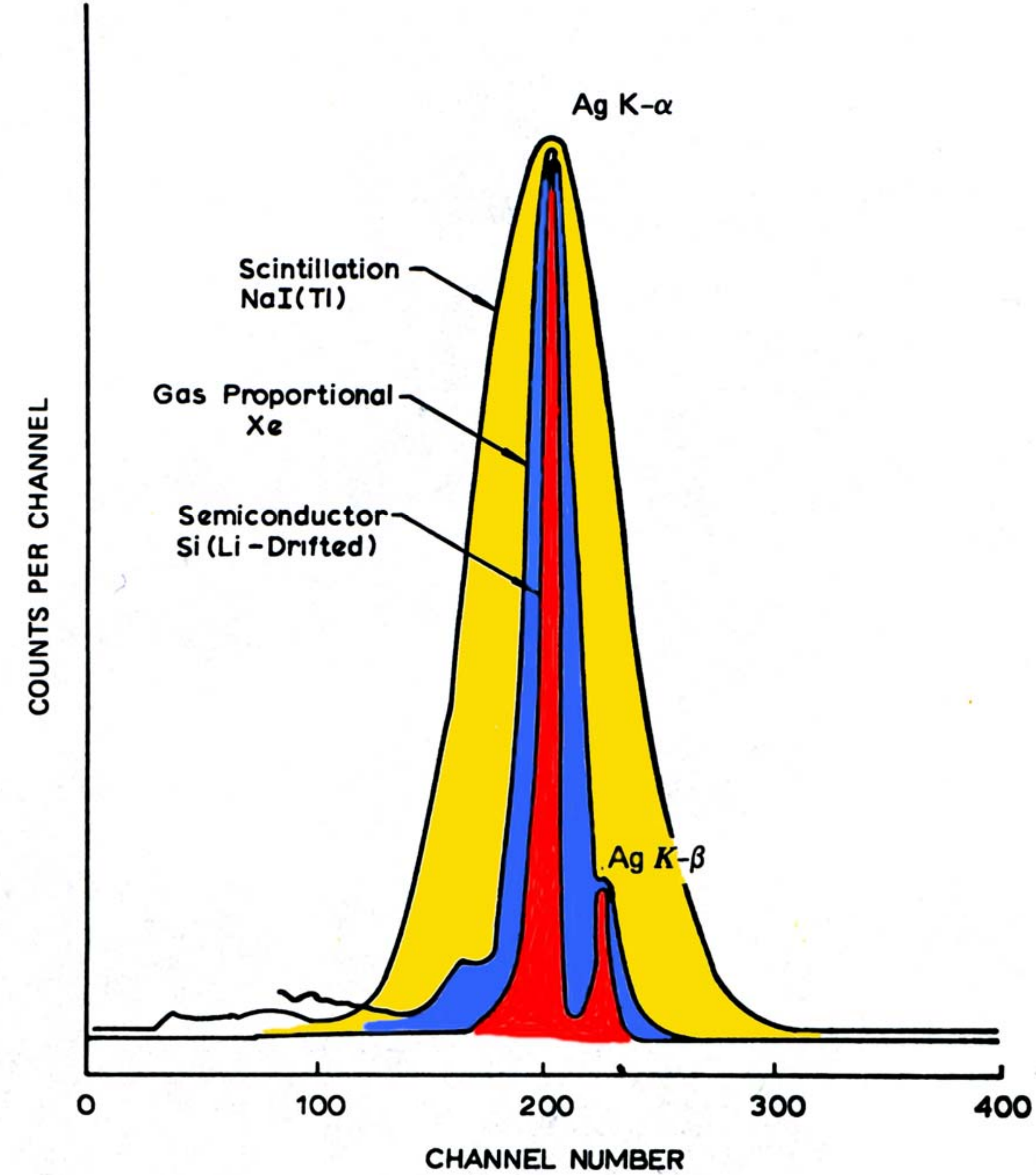


Mapping sulphates on Michelangelo's David using portable EDXRF (from "Exploring David: diagnostic tests and state of conservation," edited by S. Bracci et al., GIUNTI, Florence, 2004)

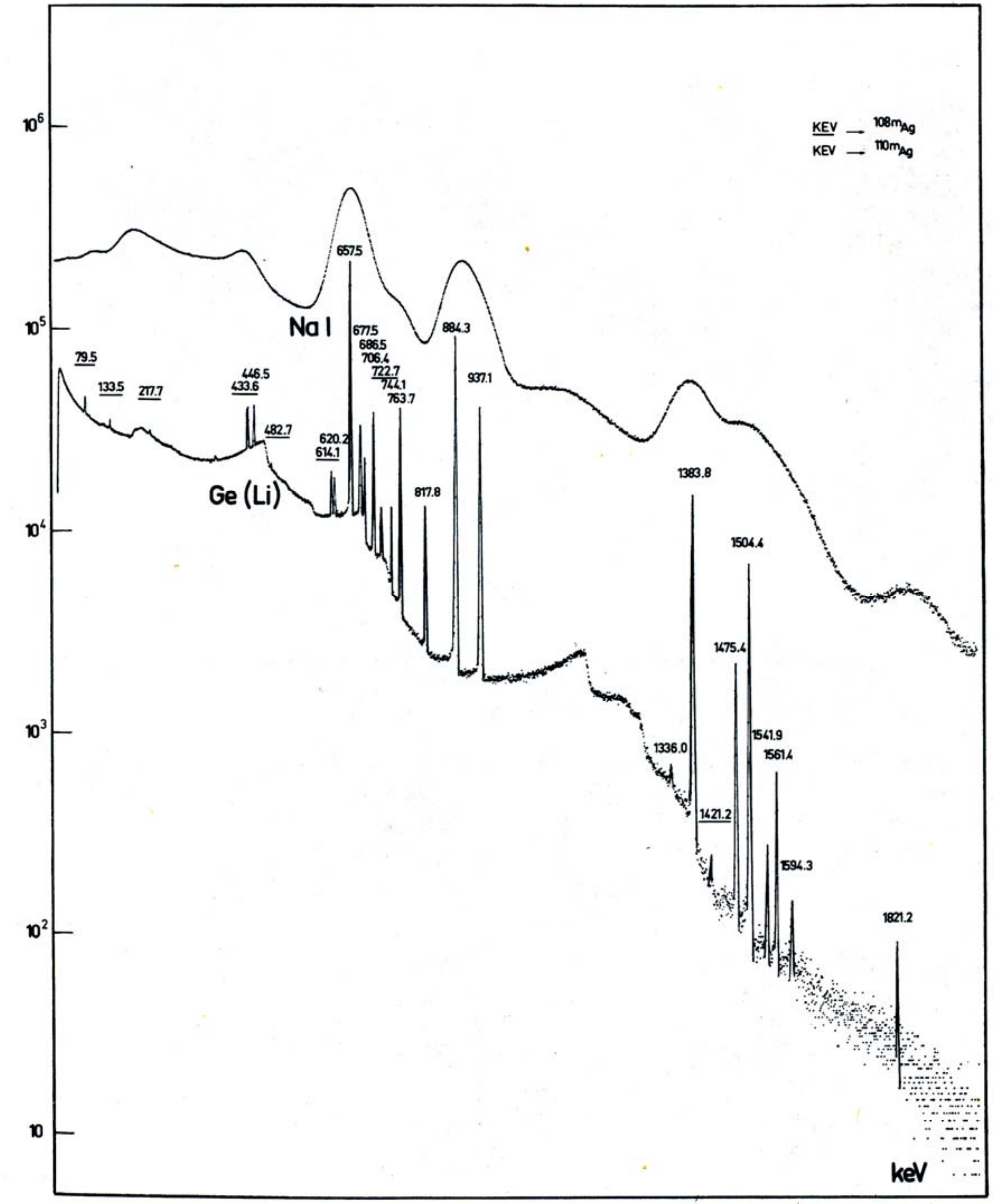
Giovanni Buccolieri, Alfredo Castellano, Marina Donativi, Stefano Quarta

Universita di Lecce, Dipartimento di Scienza dei Materiali

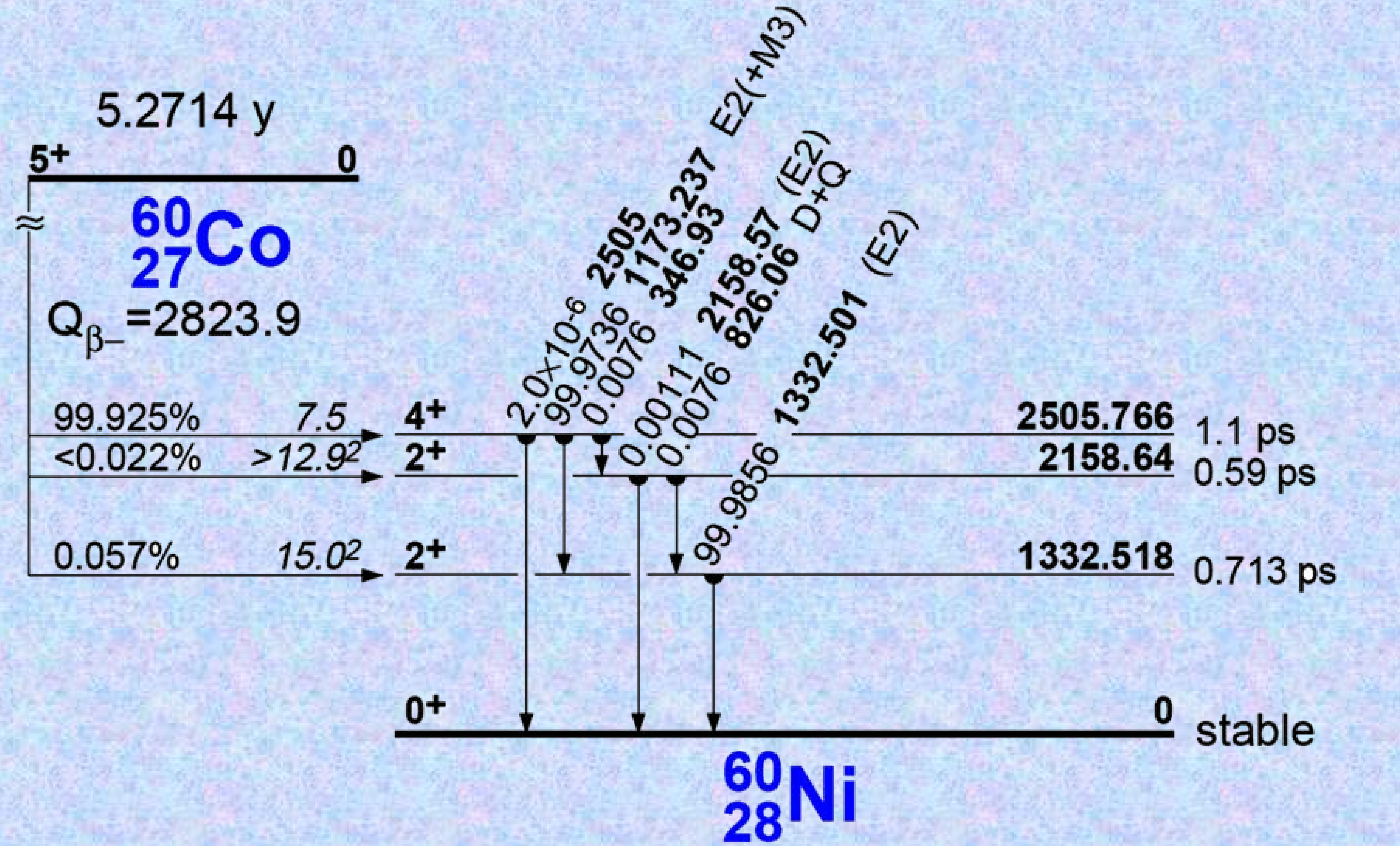
PIXE investigation of funeral mask of Queen Sat-Djehuti, ~1650 b.C.



Ag K-α
Scintillation
NaI(Tl)
Gas Proportional
Xe
Semiconductor
Si (Li-Drifted)
Ag K-β
COUNTS PER CHANNEL
0
100
200
300
400
CHANNEL NUMBER

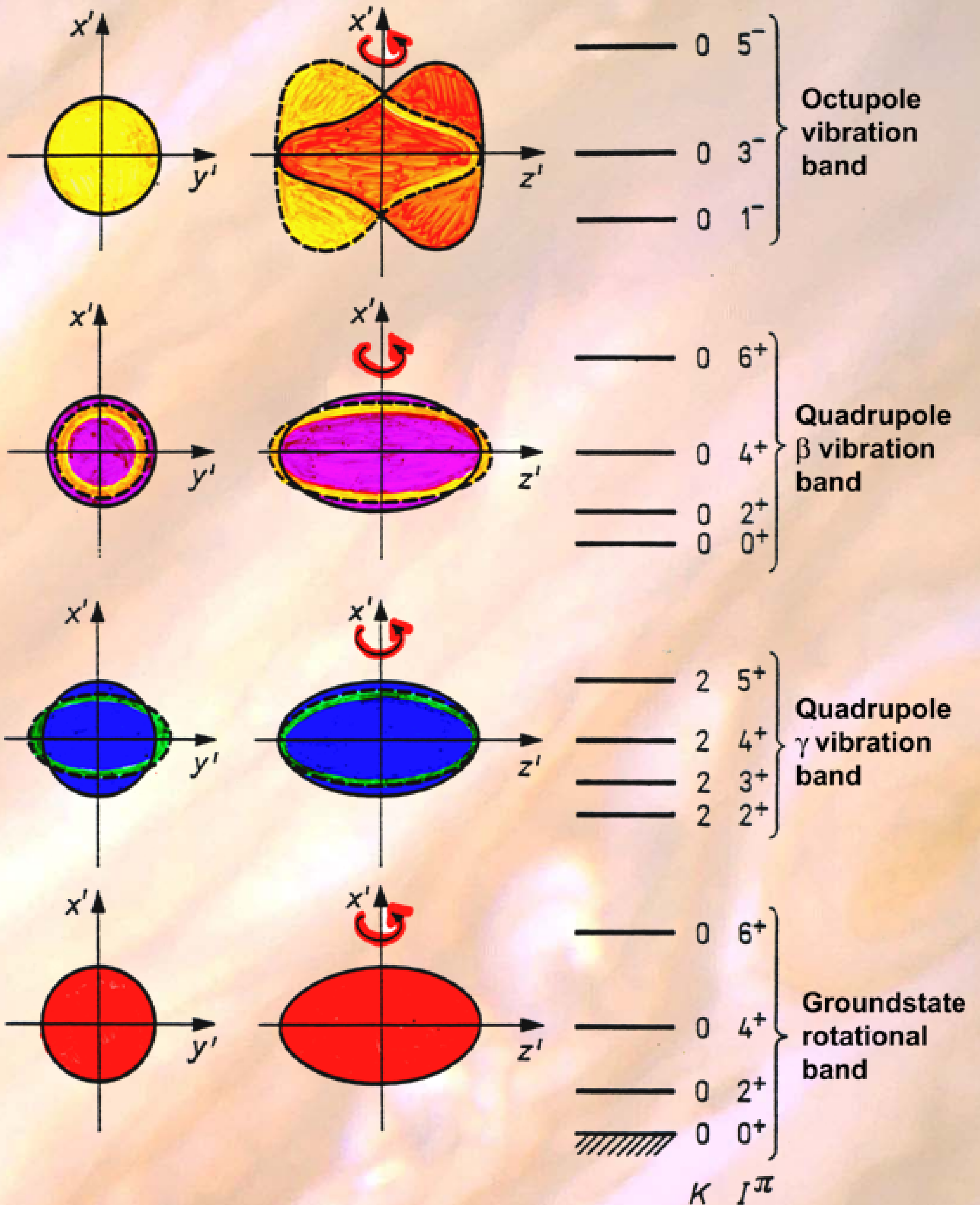


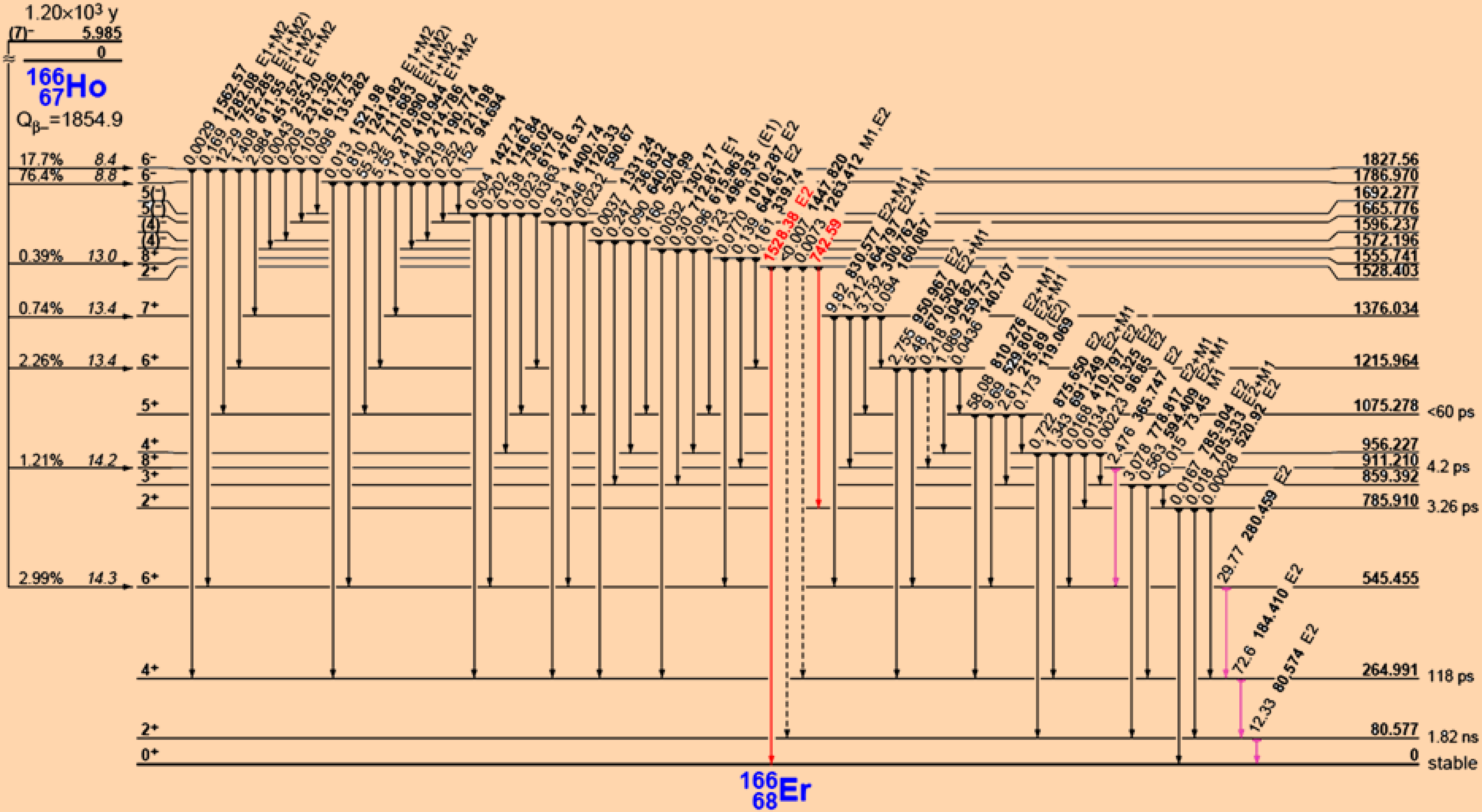
KEV → 108mAg
KEV → 110mAg
10^6
10^5
10^4
10^3
10^2
10
Na I
Ge (Li)
79.5
133.5
217.7
446.5
433.6
482.7
620.2
614.1
657.5
677.5
686.5
706.4
722.7
744.1
763.7
817.8
884.3
937.1
1336.0
1383.8
1421.2
1475.4
1504.4
1541.9
1561.4
1594.3
1821.2
keV



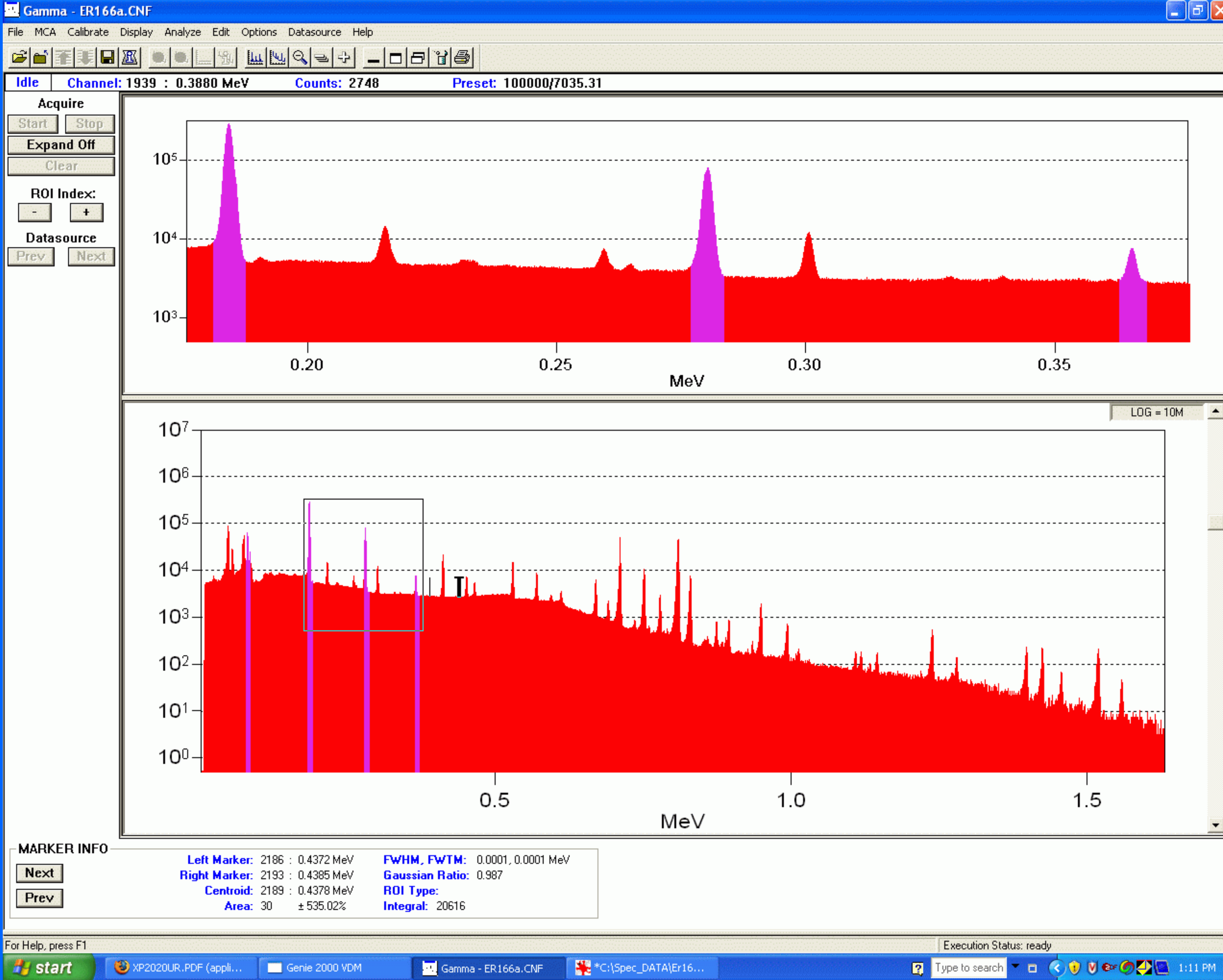
5.2714 y
5+
0
60 27 Co
Qβ– =2823.9
99.925%
7.5
<0.022%
>12.9²
0.057%
15.0²
4+
2+
2+
0+
2.0×10-6 2505
99.9736 1173.237 E2(+M3)
0.0076 346.93
0.00111 2158.57 (E2)
0.0076 826.06 D+Q
99.9856 1332.501 (E2)
2505.766
1.1 ps
2158.64
0.59 ps
1332.518
0.713 ps
0
stable
60 28 Ni

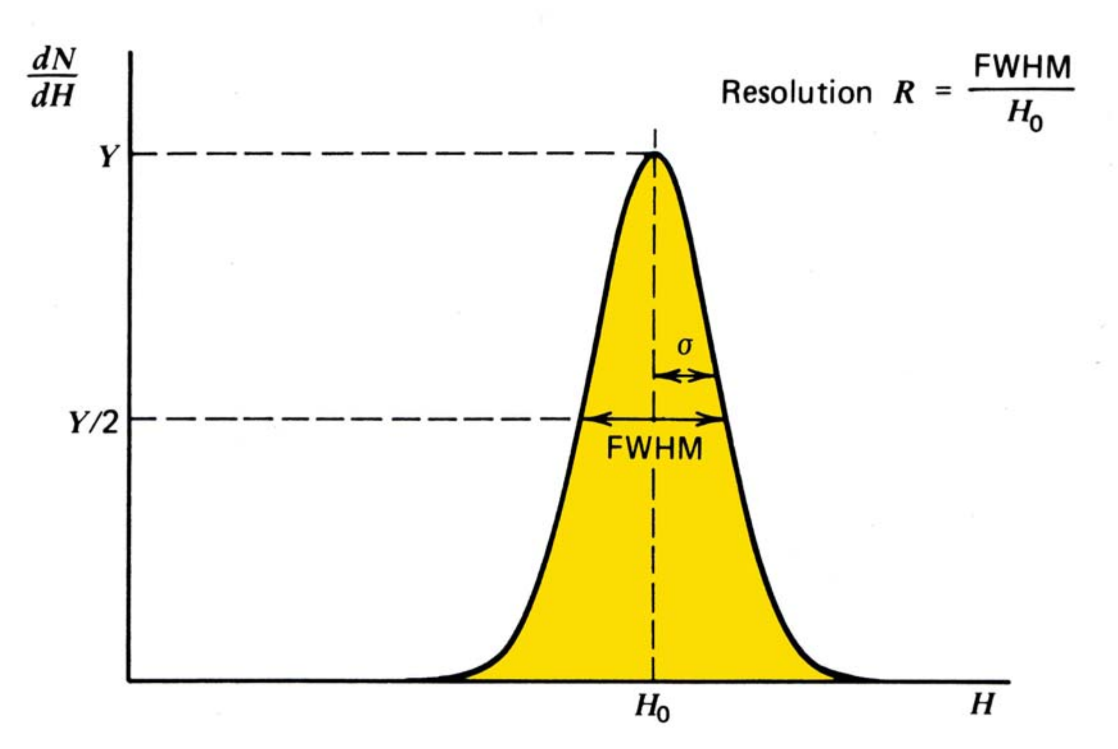
Collective model of the nucleus (liquid drop)





1.20×10³ y
(7)⁻ 5.985
0
166 67 Ho
Qβ−=1854.9
17.7% 8.4 6⁻ 1827.56
76.4% 8.8 6⁻ 1786.970
5(−) 1692.277
5(−) 1665.776
(4)⁻ 1596.237
(4)⁻ 1572.196
0.39% 13.0 8⁺ 1555.741
2⁺ 1528.403
0.74% 13.4 7⁺ 1376.034
2.26% 13.4 6⁺ 1215.964
5⁺ 1075.278 <60 ps
4⁺ 956.227
1.21% 14.2 8⁺ 911.210 4.2 ps
3⁺ 859.392
2⁺ 785.910 3.26 ps
2.99% 14.3 6⁺ 545.455
4⁺ 264.991 118 ps
2⁺ 80.577 1.82 ns
0⁺ 0 stable
166 68 Er


Gamma - ER166a.CNF
File MCA Calibrate Display Analyze Edit Options Datasource Help
Idle
Channel: 1939 : 0.3880 MeV
Counts: 2748
Preset: 100000/7035.31
Acquire
Start
Stop
Expand Off
Clear
ROI Index:
-
+
Datasource
Prev
Next
10⁵
10⁴
10³
0.20
0.25
0.30
0.35
MeV
LOG = 10M
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
10⁰
0.5
1.0
1.5
MeV
MARKER INFO
Next
Prev
Left Marker: 2186 : 0.4372 MeV
Right Marker: 2193 : 0.4385 MeV
Centroid: 2189 : 0.4378 MeV
Area: 30 ± 535.02%
FWHM, FWTM: 0.0001, 0.0001 MeV
Gaussian Ratio: 0.987
ROI Type:
Integral: 20616
For Help, press F1
Execution Status: ready
start
XP2020UR.PDF (appli...
Genie 2000 VDM
Gamma - ER166a.CNF
*C:\Spec_DATA\Er16...
Type to search
1:11 PM



Resolution $R = \frac{\text{FWHM}}{\text{H}_\text{o}}$

FWHM (Gaussian shape) $= 2.35\,\sigma$

For $\frac{\Delta \text{E}}{E} \leq 1\,\%$

$\succ$ $\text{N} \geq 55\,000$

$(= 235 \text{ x } 235)$

E corresponds to number of charge carrier pairs or photons $\rightarrow$ number N

Poisson process: fluctuations $= \sqrt{N}$ = standard deviation

pulse amplitude $\text{H}_\text{o} = \text{K} \cdot \text{N}$ $\quad \sigma = \text{K} \cdot \sqrt{N}$

$\text{FWHM} = 2.35\ \text{K} \cdot \sqrt{N}$

$$\text{R}_\text{statist} = \frac{\text{FWHM}}{\text{H}_\text{o}} = \frac{2.35\,\text{K} \cdot \sqrt{\text{N}}}{\text{K} \cdot \text{N}} = \frac{2.35}{\sqrt{\text{N}}}$$

with correlations and FANO factor: $\quad \text{R}_\text{statist} = \frac{2.35 \cdot \sqrt{\text{F}}}{\sqrt{\text{N}}}$

$$(\text{FWHM})^2_\text{total} = (\text{FWHM})^2_\text{statist} + (\text{FWHM})^2_\text{noise} + (\text{FWHM})^2_\text{drift}$$

FANO factor = correlation effect

Poisson statistics is not valid if ϵ is mostly the same in all charge carrier production processes

$$\text{F} = \frac{\text{observed variance in N}}{\text{Poisson predicted variance}}$$

	energy [MeV]	charge carrier-pairs, resp. photoelectrons	statistical error rms	full width half maximum [%]
semiconductor detector ε = 3eV / e^--hole-pair Fano-factor 0.1 – 0.16	3.0	10^6	400	0.09
	1.0	3.3×10^5	230	0.16
	0.3	10^5	127	0.30
	0.1	3.3×10^4	73	0.52
gas proportional counter ε = 30eV / ion-pair Fano-factor ~ 0.33	3.0	10^5	183	0.43
	1.0	3.3×10^4	106	0.75
	0.3	10^4	58	1.36
	0.1	3.3×10^3	33	2.35
scintillation detector ε = 300eV / photo-electron no Fano-factor !	3.0	10^4	100	2.35
	1.0	3.3×10^3	60	4.08
	0.3	10^3	30	7.40
	0.1	3.3×10^2	15	13.0