

Welcome to 3.091

Lecture 17

October 19, 2009

X-Ray Emission & Absorption

Bertha Röntgen's hand



photo credit: Wilhelm Röntgen

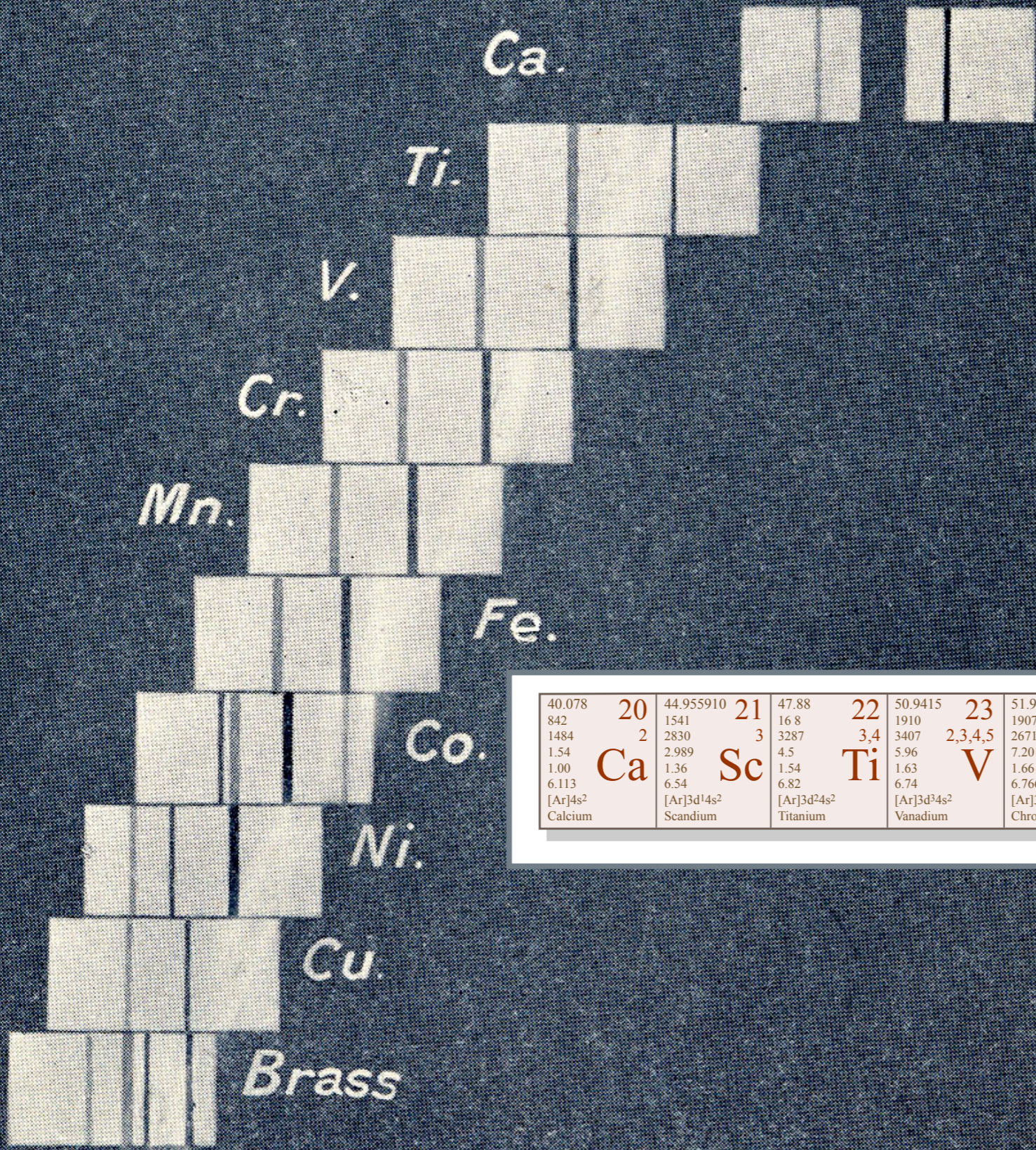
bounding surface of the metal in which the light absorption takes place are the determining factors in this displacement.

Berlin, Physikalisches Institut
der Universität, July 1913.

XCIH. *The High-Frequency Spectra of the Elements.*
*By H. G. J. MOSELEY, M.A.**

[Plate XXIII.]

IN the absence of any available method of spectrum analysis, the characteristic types of X radiation, which an atom emits when suitably excited, have hitherto been described in terms of their absorption in aluminium †. The interference phenomena exhibited by X rays when scattered by a crystal have now, however, made possible the accurate determination of the frequencies of the various types of radiation. This was shown by W. H. and W. L. Bragg ‡, who by this method analysed the line spectrum emitted by the platinum target of an X-ray tube. C. G. Darwin and the author § extended this analysis and also examined the continuous spectrum, which in this case constitutes the greater part of the radiation. Recently Prof. Bragg || has also



40.078	20	44.955910	21	47.88	22	50.9415	23	51.9961	24	54.93805	25	55.847	26	58.93320	27	58.6934	28	63.546	29	65.39	30
842		1541		16 8		1910		1907		1246		1538		1495		1455		1084.62		419.53	
1484	2	2830	3	3287	3,4	3407	2,3,4,5	2671	2,3,6	2061	2,3,4,6,7	2861	2,3	2927	2,3	2913	2,3	2562	1,2	907	2
1.54	Ca	2.989	Sc	4.5	Ti	5.96	V	7.20	Cr	7.47	Mn	7.86	Fe	8.92	Co	8.90	Ni	8.94	Cu	7.14 ^{25%}	Zn
1.00		1.36		1.54		1.63		1.66		1.55		1.83		1.88		1.91		1.90		1.65	
6.113		6.54		6.82		6.74		6.766		7.435		7.870		7.86		7.635		7.726		9.394	
[Ar]4s ²		[Ar]3d ¹ 4s ²		[Ar]3d ² 4s ²		[Ar]3d ³ 4s ²		[Ar]3d ⁵ 4s ¹		[Ar]3d ⁵ 4s ²		[Ar]3d ⁶ 4s ²		[Ar]3d ⁷ 4s ²		[Ar]3d ⁸ 4s ²		[Ar]3d ¹⁰ 4s ¹		[Ar]3d ¹⁰ 4s ²	
Calcium		Scandium		Titanium		Vanadium		Chromium		Manganese		Iron		Cobalt		Nickel		Copper		Zinc	

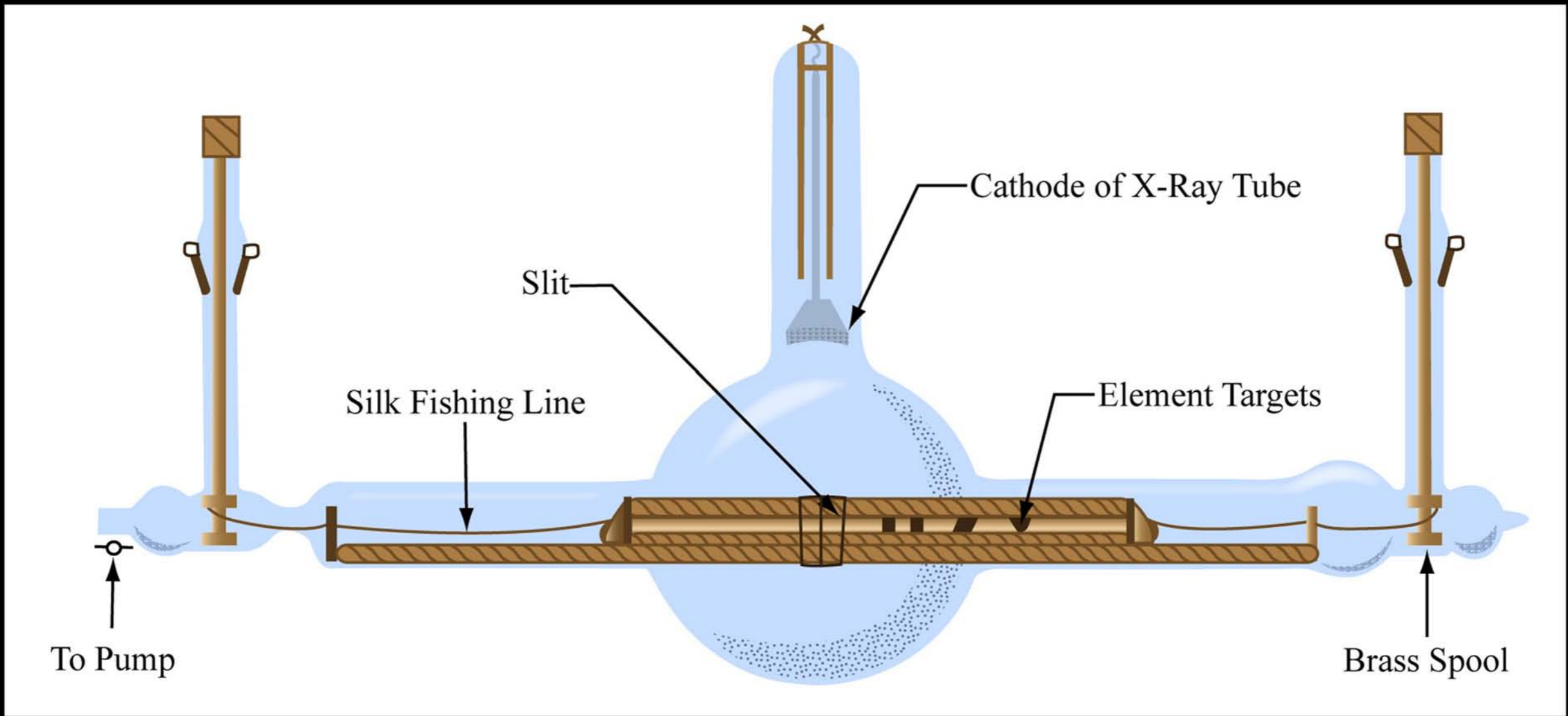


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effect in the case of many metals and alloys are subject to variations as great as an octave and more. This difficulty is all the more real in that as yet we are not in a position to determine what influences on and in the extremely thin bounding surface of the metal in which the light absorption takes place are the determining factors in this displacement.

Berlin, Physikalisches Institut
der Universität, July 1913.

XCI. *The High-Frequency Spectra of the Elements.*

By H. G. J. MOSELEY, M.A.*

[Plate XXIII.]

IN the absence of any available method of spectrum analysis, the characteristic types of X radiation, which an atom emits when suitably excited, have hitherto been described in terms of their absorption in aluminium †. The interference phenomena exhibited by X rays when scattered by a crystal have now, however, made possible the accurate determination of the frequencies of the various types of radiation. This was shown by W. H. and W. L. Bragg ‡, who by this method analysed the line spectrum emitted by the platinum target of an X-ray tube. C. G. Darwin and the author § extended this analysis and also examined the continuous spectrum, which in this case constitutes the greater part of the radiation. Recently Prof. Bragg || has also determined the wave-lengths of the strongest lines in the spectra of nickel, tungsten, and rhodium. The electrical methods which have hitherto been employed are, however, only successful where a constant source of radiation is available. The present paper contains a description of a method of photographing these spectra, which makes the analysis of the X rays as simple as any other branch of spectroscopy. The author intends first to make a general survey of the principal types of high-frequency radiation, and then to examine the spectra of a few elements in greater detail and with greater accuracy. The results already obtained show that such data have an important bearing on the question of

the internal structure of the atom, and strongly support the views of Rutherford and of Bohr.

* Communicated by Prof. E. Rutherford, F.R.S.

† Cf. Barkla, *Phil. Mag.* xxii. p. 396 (1911).

‡ *Proc. Roy. Soc. A.* lxxxviii. p. 428 (1913).

§ *Phil. Mag.* xxvi. p. 210 (1913).

|| *Proc. Roy. Soc. A.* lxxxix. p. 246 (1913).

The reason for introducing this particular constant will be given later. It is at once evident that Q increases by a constant amount as we pass from one element to the next, using the chemical order of the elements in the periodic system. Except in the case of nickel and cobalt*, this is also the order of the atomic weights. While, however, Q increases uniformly the atomic weights vary in an apparently arbitrary manner, so that an exception in their order does not come as a surprise. We have here a proof that there is in the atom a fundamental quantity, which increases by regular steps as we pass from one element to the next. This quantity can only be the charge on the central positive nucleus, of the existence of which we already have definite proof. Rutherford has shown, from the magnitude of the scattering of α particles by matter, that this nucleus carries a + charge approximately equal to that of $\frac{A}{2}$ electrons, where A is the atomic weight. Barkla, from the scattering of X rays by matter, has shown that the number of electrons in an atom is roughly $\frac{A}{2}$, which for an electrically neutral atom comes to the same thing. Now atomic weights increase on the average by about 2 units at a time, and this strongly suggests the view that N increases from atom to atom always by a single electronic unit. We are therefore led by experiment to the view that N is the same as the number of the place occupied by the element in the periodic system. This atomic number is then for H 1 for He 2 for Li 3... for Ca 20... for Zn 30, &c. This theory was originated by Broek † and since used by Bohr ‡. We can confidently predict that in the few cases in which the order of the atomic weights A clashes with the chemical order of the periodic system, the chemical properties are governed by N ; while A is itself probably a complicated function of N . The very close similarity between the X-ray spectra of the different elements shows that these radiations originate inside the atom, and have no direct connexion with the complicated light-spectra and chemical properties which are governed by the structure of its surface.

39.948

-189.35

-185.85

1.784

-

15.759

[Ne]3s²p⁶

Argon

18

Ar

39.0983

63.38

759

0.86

0.82

4.341

[Ar]4s¹

Potassium

19

1
K

58.93320

1495

2927

8.92

1.88

7.86

[Ar]3d⁷4s²

Cobalt

27

2,3
Co

58.6934

1455

2913

8.90

1.91

7.635

[Ar]3d⁸4s²

Nickel

28

2,3
Ni

127.60

449.51

988

6.25

2.1

9.009

[Kr]4d¹⁰5s²p⁴

Tellurium

52

-2,4,6
Te

126.90447

113.7

184.4

4.93

2.66

10.451

[Kr]4d¹⁰5s²p⁵

Iodine

53

±1,5,7
I

238.0289

1135

4131

19.05+0.02

1.38

6.05

[Rn]5f³6d¹7s²

Uranium

92

3,4,5,6
U

(237.0482)

644

-

20.45

1.36

6.19

[Rn]5f⁴6d¹7s²

Neptunium

93

3,4,5,6
Np

We will now examine the relation

$$Q = \sqrt{\frac{\nu}{\frac{3}{4}\nu_0}}$$

more closely. So far the argument has relied on the fact that Q is a quantity which increases from atom to atom by equal steps. Now Q has been obtained by multiplying $\nu^{\frac{1}{2}}$ by a constant factor so chosen as to make the steps equal to unity. We have, therefore,

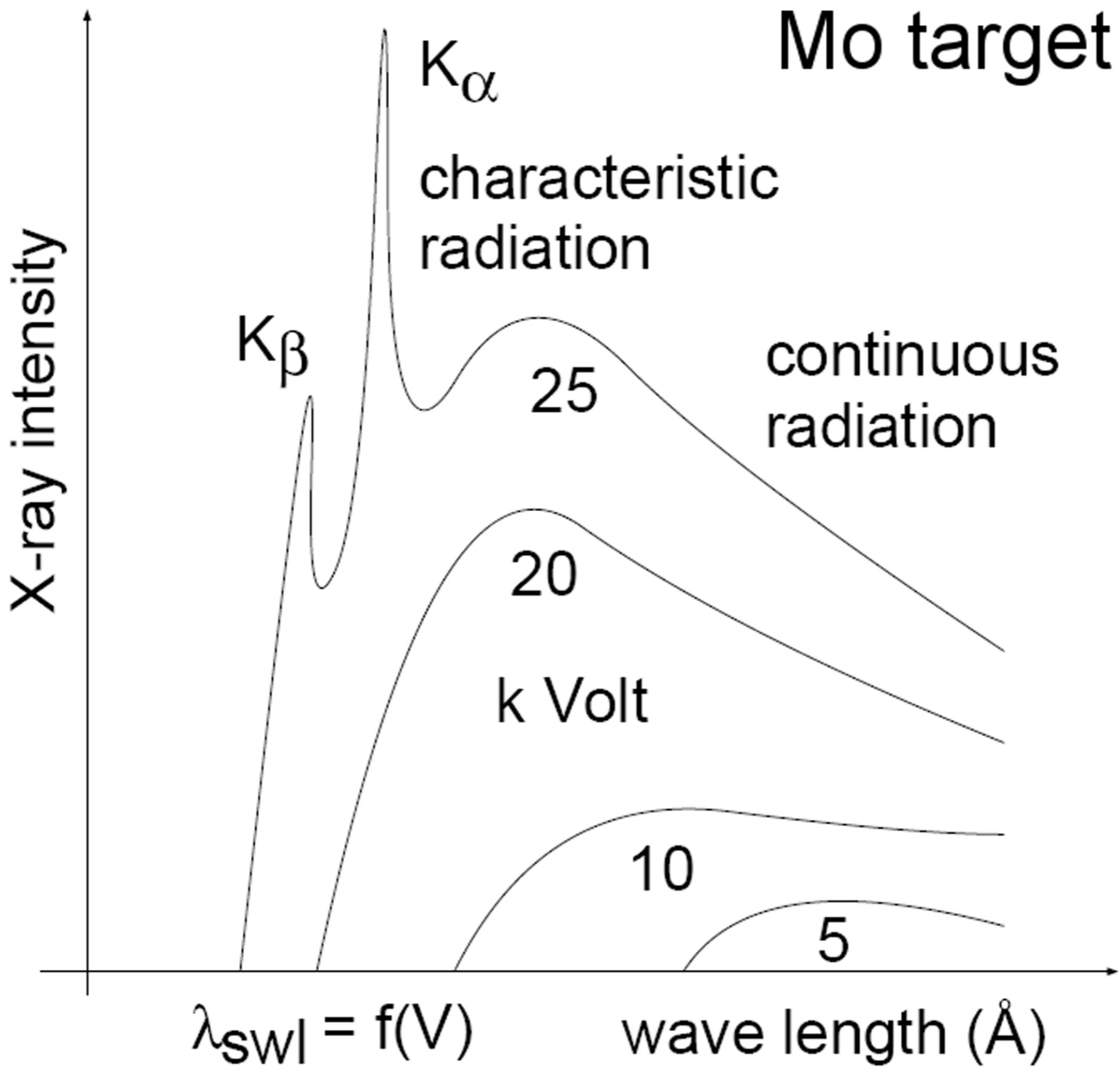
$$Q = N - k,$$

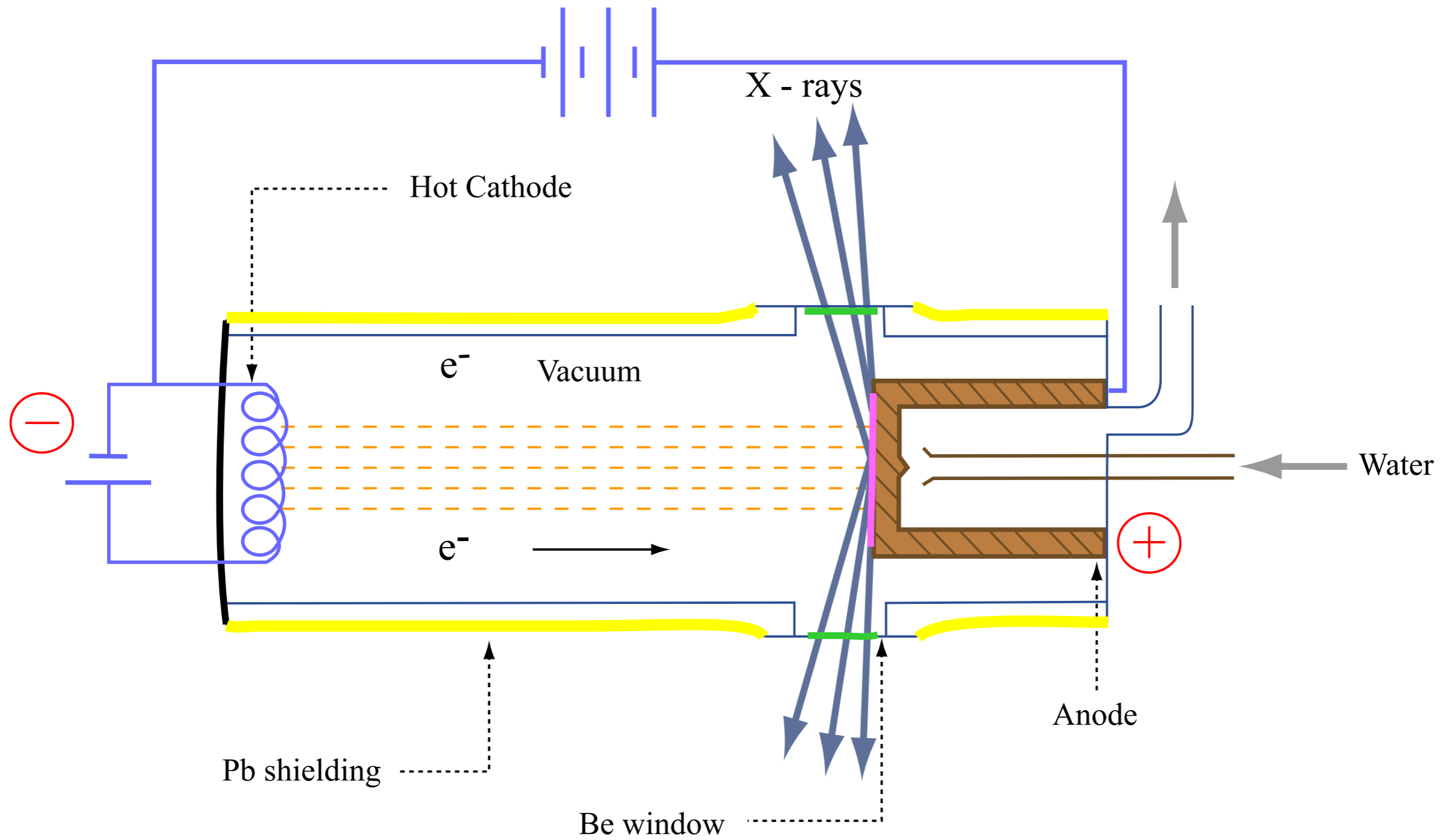
where k is a constant. Hence the frequency ν varies as $(N - k)^2$. If N for calcium is really 20 then $k = 1$.

There is good reason to believe that the X-ray spectra with which we are now dealing come from the innermost ring of electrons*.



Henry G.W. Moseley





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1 IA IA											18 VIII 0									
1.00794 -259.34 -252.87 0.0899 2.20 13.598 1s ¹ Hydrogen	9.012182 1287 2471 1.8477 1.57 9.322 [He]2s ² Lithium	4 2 2											4.002602 -272.2 ²⁶ atm -268.93 0.1785 - 24.587 1s ² Helium							
6.941 180.5 1342 0.534 0.98 5.392 [He]2s ¹ Lithium	9.012182 1287 2471 1.8477 1.57 9.322 [He]2s ² Beryllium	3 1 1	2 IIA IIA											10.811 2075 4000 2.31 2.04 8.298 [He]2s ² p ¹ Boron	12.011 4492 ^{TP} 3825 ^{SP} 2.25 2.55 11.260 [He]2s ² p ² Carbon	14.00674 -210.00 -195.79 1.25046 3.04 14.534 [He]2s ² p ³ Nitrogen	15.9994 -218.79 -182.95 1.429 3.44 17.422 [He]2s ² p ⁴ Oxygen	16 VIA VIA	17 VIIA VIIA	18 VIII VIII
22.989768 97.72 883 0.97 0.93 5.139 [Ne]3s ¹ Sodium	24.3050 650 1090 1.74 1.31 7.646 [Ne]3s ² Magnesium	11 1 1	2 IIA IIA	3 IIIA IIIB	4 IVA IVB	5 VA VB	6 VIA VIB	7 VIIA VIIIB	8 VIII VIII	9 VIII VIII	10 VIII VIII	11 IB IB	12 IIB IIB	26.981539 660.32 2519 2.702 1.61 5.986 [Ne]3s ² p ¹ Aluminum	28.0855 1414 3265 2.33 1.90 8.151 [Ne]3s ² p ² Silicon	30.973762 44.15 277 1.82 2.19 10.486 [Ne]3s ² p ³ Phosphorus	32.066 115.21 444.60 2.07 2.58 10.360 [Ne]3s ² p ⁴ Sulfur	35.4527 -101.5 -34.04 3.214 3.16 12.967 [Ne]3s ² p ⁵ Chlorine	37.994732 -189.35 -185.85 1.784 - 15.759 [Ne]3s ² p ⁶ Argon	
39.0983 63.38 759 0.86 0.82 4.341 [Ar]4s ¹ Potassium	40.078 842 1484 1.54 1.00 6.113 [Ar]4s ² Calcium	19 1 1	20 2 2	21 3 3	22 3,4 3,4	23 2,3,4,5 2,3,4,5	24 2,3,6 2,3,6	25 2,3,4,6,7 2,3,4,6,7	26 2,3 2,3	27 2,3 2,3	28 2,3 2,3	29 1,2 1,2	30 2 2	31 3 3	32 4 4	33 ±3,5 ±3,5	34 -2,4,6 -2,4,6	35 ±1,5 ±1,5	36 3,74 3,74	
85.4678 39.31 688 1.532 0.82 4.177 [Kr]5s ¹ Rubidium	87.62 777 1382 2.6 0.95 5.695 [Kr]5s ² Strontium	37 1 1	38 2 2	39 3 3	40 4 4	41 3,5 3,5	42 2,3,4,5,6 2,3,4,5,6	43 7 7	44 2,3,4,6,8 2,3,4,6,8	45 2,3,4 2,3,4	46 2,4 2,4	47 1 1	48 2 2	49 3 3	50 2,4 2,4	51 ±3,5 ±3,5	52 -2,4,6 -2,4,6	53 ±1,5,7 ±1,5,7	54 -108.04 -108.04	
132.90543 28.44 671 1.879 0.79 3.894 [Xe]6s ¹ Cesium	137.327 727 1897 3.594 0.89 5.212 [Xe]6s ² Barium	55 1 1	56 2 2	57 3 3	58 4 4	59 5 5	60 2,3,4,5,6 2,3,4,5,6	61 2,3,4,6,8 2,3,4,6,8	62 2,3,4,6 2,3,4,6	63 2,3,4 2,3,4	64 2,4 2,4	65 1,3 1,3	66 1,2 1,2	67 1,2 1,2	68 2,4 2,4	69 3,5 3,5	70 2,4 2,4	71 ±1,3,5,7 ±1,3,5,7	72 9.7 9.7	
(223.0197) 27 677 0.7 - [Rn]7s ¹ Francium	(226.0254) 700 <1140 5.8 0.9 5.279 [Rn]7s ² Radium	87 1 1	88 2 2	89 3 3	90 4 4	91 3 3	92 4 4	93 5 5	94 6 6	95 7 7	96 8 8	97 9 9	98 10 10	99 11 11	100 12 12	101 13 13	102 14 14	103 15 15	104 16 16	

Window

Shielding

* 140.115 799 3424 6.770 1.12 5.466 [Xe]4f ¹⁵ d ¹ 6s ² Cerium	140.90765 931 3510 6.773 1.13 5.422 [Xe]4f ¹⁶ 6s ² Praseodymium	144.24 1016 3066 7.00 1.14 5.489 [Xe]4f ¹⁶ 6s ² Neodymium	(144.9127) 1042 3000 7.254 1.13 5.554 [Xe]4f ¹⁶ 6s ² Promethium	150.36 1072 1790 7.536 1.17 5.631 [Xe]4f ¹⁶ 6s ² Samarium	151.965 822 1596 5.244 1.20 5.666 [Xe]4f ¹⁶ 6s ² Europium	157.25 1314 3264 7.901 1.2 6.141 [Xe]4f ¹⁵ d ¹ 6s ² Gadolinium	158.92534 1359 3221 8.230 1.22 5.842 [Xe]4f ¹⁶ 6s ² Terbium	162.50 1411 2561 8.551 1.22 5.927 [Xe]4f ¹⁶ 6s ² Dysprosium	164.93032 1472 2694 8.80 1.23 6.018 [Xe]4f ¹⁶ 6s ² Holmium	167.26 1529 9.066 8.80 1.23 6.101 [Xe]4f ¹⁶ 6s ² Erbium	168.93421 1545 2862 9.321 6.18436 [Xe]4f ¹⁶ 6s ² Thulium	173.04 824 1194 9.666 1.1 6.25394 [Xe]4f ¹⁶ 6s ² Ytterbium	174.967 1663 3393 9.84 1.27 5.42589 [Xe]4f ¹⁵ d ¹ 6s ² Lutetium
** 232.0381 1750 4788 11.72 1.3 6.08 [Rn]6d ² 7s ² Thorium	231.03588 1572 4131 15.37 1.5 5.89 [Rn]5f ² 6d ¹ 7s ² Protactinium	238.0289 1135 4131 19.05+0.02 1.38 6.05 [Rn]5f ³ 6d ¹ 7s ² Uranium	(237.0482) 644 20.45 19.816 1.28 6.19 [Rn]5f ⁴ 6d ¹ 7s ² Neptunium	(244.0642) 640 3228 13.67 1.3 5.993 [Rn]5f ⁶ 7s ² Plutonium	(243.0614) 1176 2507 13.67 1.3 6.02 [Rn]5f ⁷ 7s ² Americium	(247.0703) 1345 1050 14.78 1.3 6.23 [Rn]5f ⁷ 6d ¹ 7s ² Curium	(247.0703) 1050 14.78 1.3 6.23 [Rn]5f ⁹ 7s ² Berkelium	(251.0796) 900 1527 13.3 1.3 6.30 [Rn]5f ¹⁰ 7s ² Californium	(252.083) 860 1527 13.3 1.3 6.42 [Rn]5f ¹¹ 7s ² Einsteinium	(257.0951) 860 1527 13.3 1.3 6.50 [Rn]5f ¹² 7s ² Fermium	(258.10) 827 1527 13.3 1.3 6.58 [Rn]5f ¹³ 7s ² Mendelevium	(259.1009) 827 1527 13.3 1.3 6.65 [Rn]5f ¹⁴ 7s ² Nobelium	(252.11) 1627 1527 13.3 1.3 6.65 [Rn]5f ¹⁴ 6d ¹ 7s ² Lawrencium

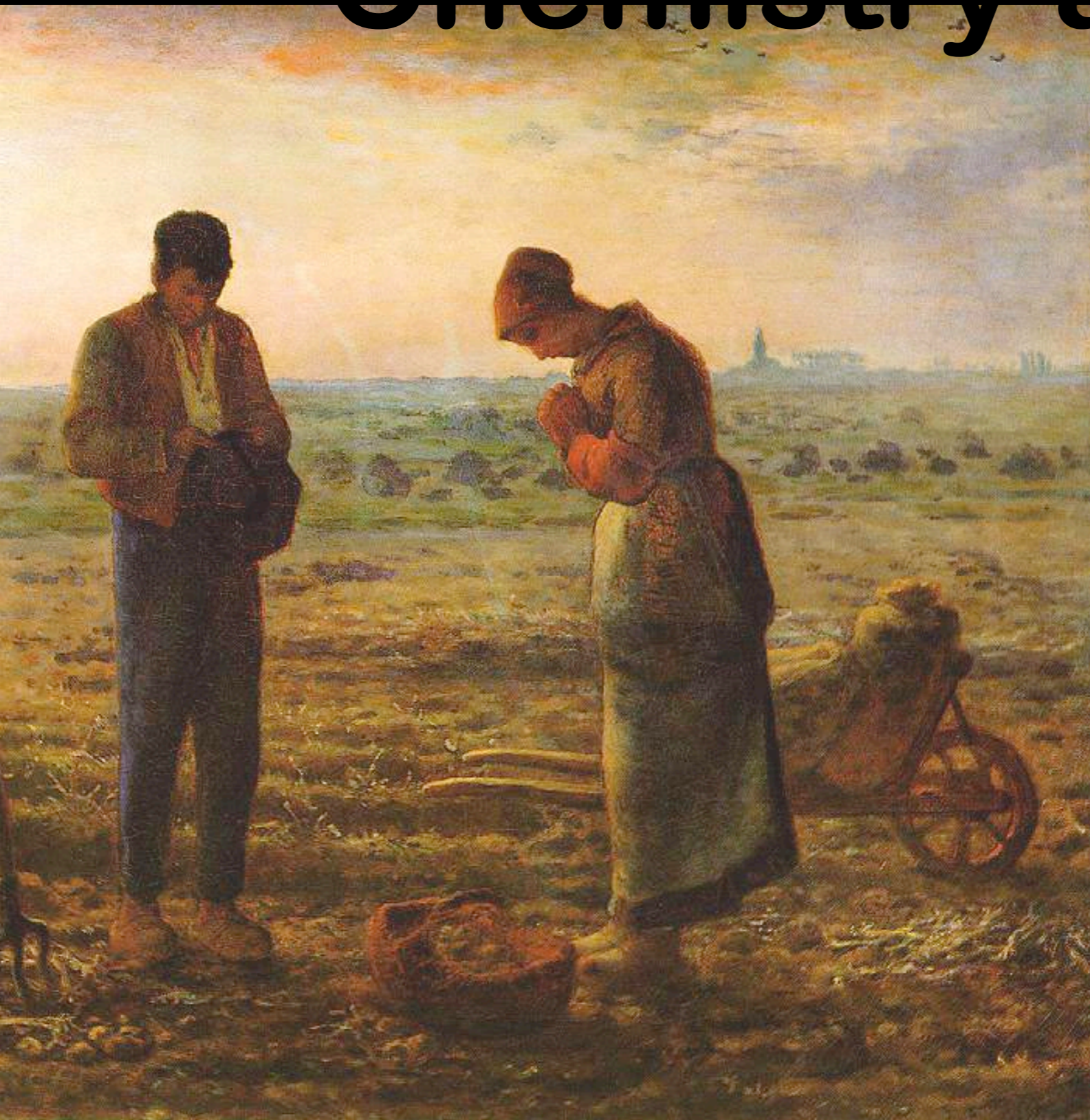
The Angelus

1857-1859

Jean-François Millet



Ornamenti e

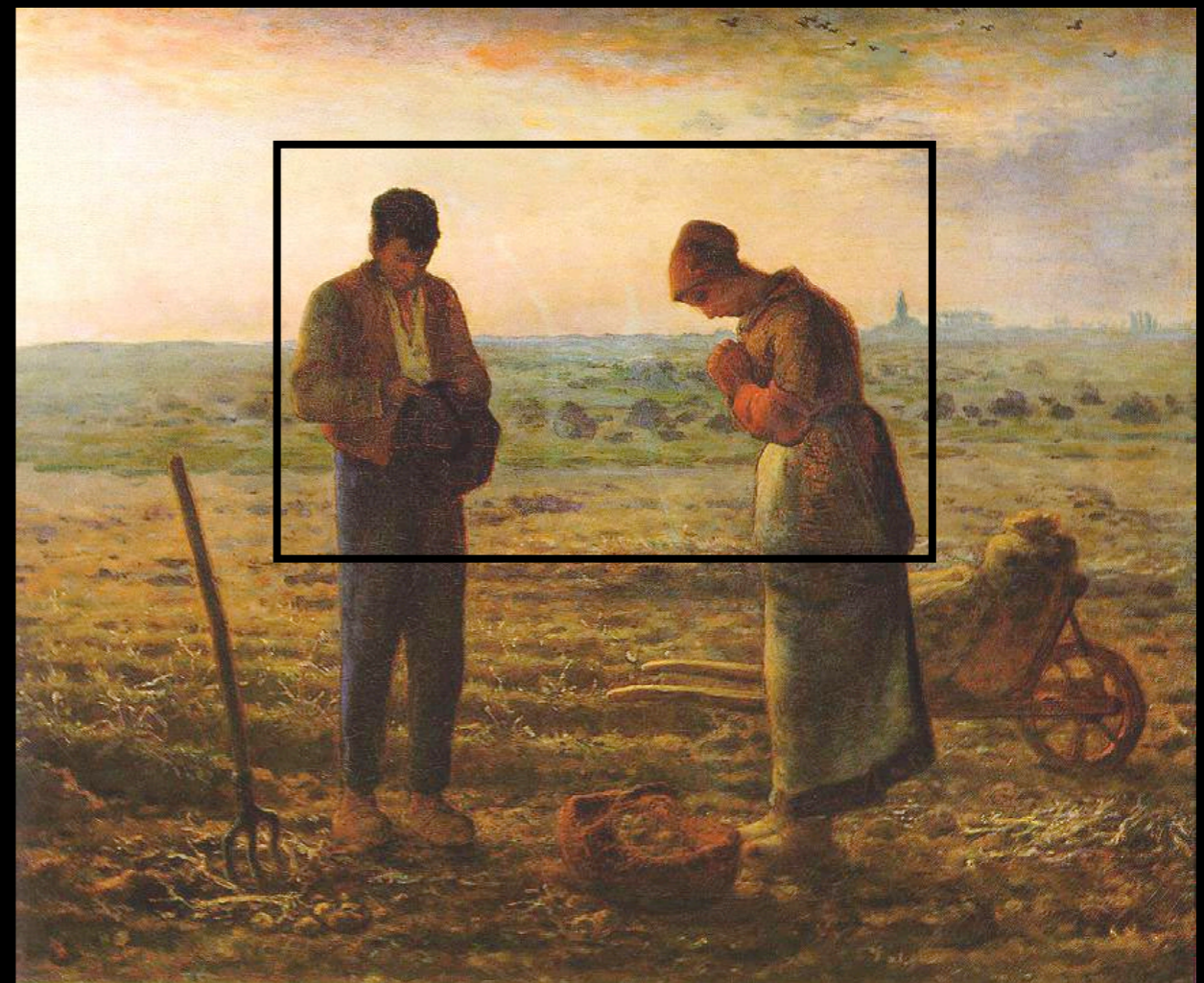


**“Adorazione del Bambino”
Fra’ Bartolomeo
Galleria Borghese
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The Hallucinogenic Toreador

Salvador Dalí

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