Welcome to 3.091

Lecture 4

September 16, 2009

Matter/Energy Interactions: Atomic Spectra

3.091 Periodic Table Quiz

1																	2
3	4											5	6	7	8	9	10
11	12											13	14	15	16	17	18
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
87	88	89															

Name ____________ Grade ______ /10

3.091 Introduction to Solid State Chemistry

DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

poly (oxyethylence methacrylate) -*b*- poly (lau

FALL TERM 2006

archives

LECTURE NOTES

1	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF	6	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF
2	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF	7	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF
3	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF	8	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF
4	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF	9	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF
5	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF	10	Notes Notes in PDF	Idle Mind Solutions Idle Mind Solutions in PDF

Supplement

Supplement in PDF

Idle Mind Questions

Idle Mind Questions in PDF

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- Coursework Fall 2004

- September Lecture Vide
- October Lecture Videos
- November Lecture Videc
- December Lecture Videc

3.091 - Introduction to Solid State Chemistry

Lecture Notes No. 1

ATOMIC AND ELECTRONIC STRUCTURE

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Sources for Further Reading:

1. Davies, D.A., Waves, Atoms and Solids, Longman, 1978.
2. DeKock, R.L., Chemical Structure and Bonding, Benjamin, 1980.
3. Brown, T.L., Chemistry, The Central Science, 5th Ed., Prentice Hall, 1991.

* *

1. ATOMS

The familiar model of an atom is that of a small nucleus composed of protons and neutrons surrounded by rapidly moving electrons. Typically, the atomic diameter is on the order of 10^{-10} m while that of the nucleus is on the order of 10^{-15} m. Protons and neutrons have about the same mass (1.00728 and 1.00867 amu respectively) and each is about 1800 times as heavy as an electron. A neutron is electrically neutral, but a proton has a positive charge ($+1.6 \times 10^{-19}$ coulomb*) which is exactly the opposite of the negative charge of an electron. In a neutral atom, the number of electrons around the nucleus equals the number of protons in the nucleus.

The number of protons in the nucleus (the "atomic number", Z) characterizes a chemical element. Atoms of a given *element* all have the same number of protons, yet may have different masses. The atomic mass number of an atom, A, is given by $A = Z + N$, where N is the number of neutrons in the nucleus. Since an element is characterized solely by Z, it follows that atoms of a given chemical element may have a varying number of neutrons. Subspecies of chemical elements with the same Z but differing N and A are called *isotopes*. The atomic weight of an element is the weighted average of the atomic masses of the various naturally occurring isotopes of the element, and the atomic weight scale is based on a value of exactly 12, after the carbon isotope that has an atomic mass number of 12.

2. NUCLEI

The nucleus of an atom weighs less than the sum of the weights of its isolated component particles. The difference between the actual mass and that of the

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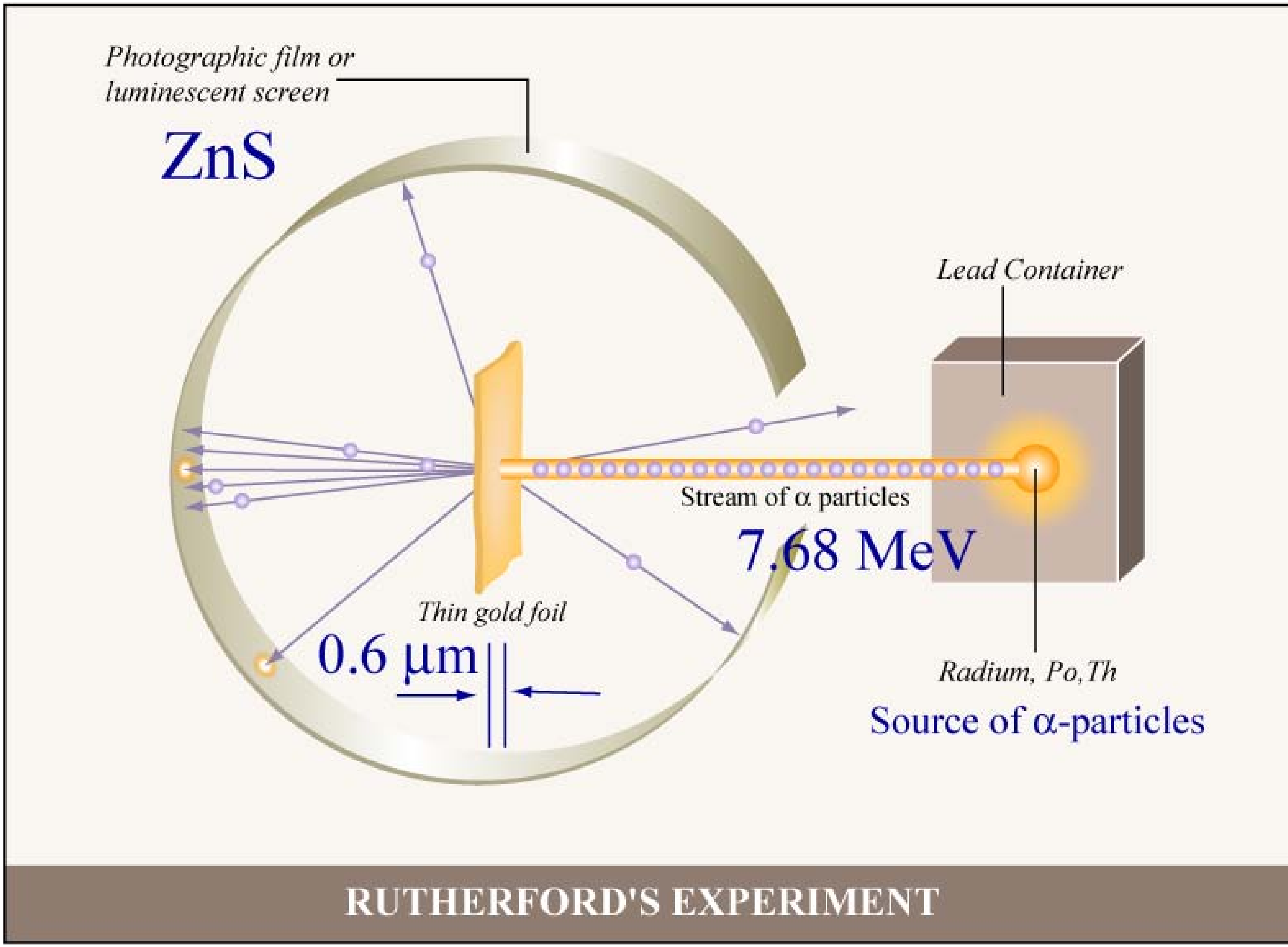
*Generally adopted International Unit System.

Rutherford-Geiger-Marsden experiment



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Bohr Postulates for the Hydrogen Atom

1. Rutherford atom is correct
2. Classical EM theory not applicable to orbiting e^-
3. Newtonian mechanics applicable to orbiting e^-
4. $E_{electron} = E_{kinetic} + E_{potential}$
5. e^- energy quantized through its angular momentum:

   $L = mvr = nh/2\pi, \quad n = 1, 2, 3, \ldots$
6. Planck-Einstein relation applies to e^- transitions:

   $\Delta E = E_f - E_i = h\nu = hc/\lambda$

   $c = \nu\lambda$

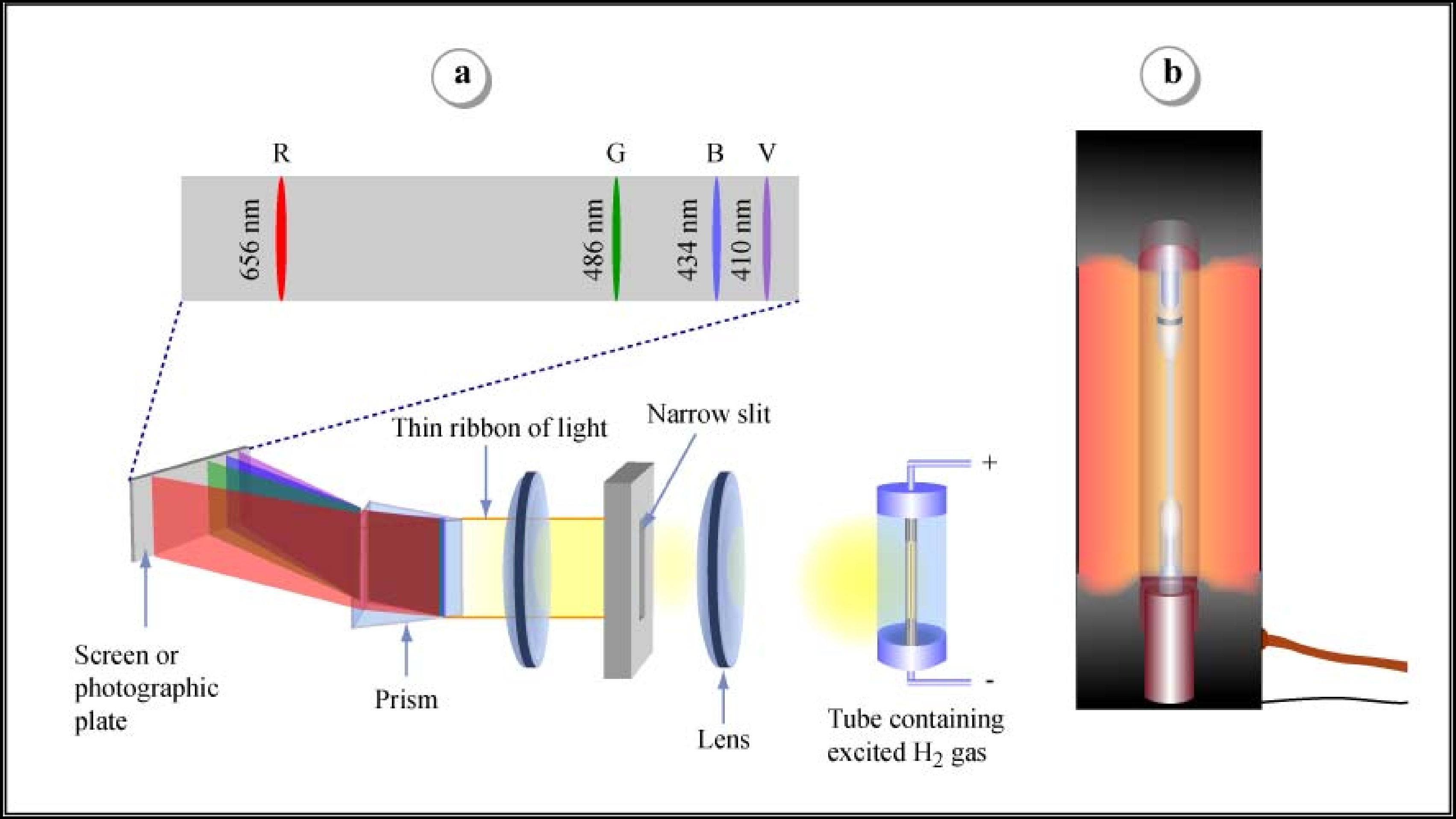
18	Bohr magneton	$\mu_B = e\hbar/2m_e$	$9.274\,015\,4(31) \times 10^{-24}$	$J\,T^{-1}$	0.34
19	Nuclear magneton	$\mu_N = e\hbar/2m_p$	$5.050\,786\,6(17) \times 10^{-27}$	$J\,T^{-1}$	0.34
20	Fine structure constant	$\alpha = \mu_0 ce^2/2h$	$7.297\,353\,08(33) \times 10^{-3}$		0.045
21	Inverse fine structure constant	$1/\alpha$	137.035 989 5(61)		0.045
22	Rydberg constant	$R_\infty = m_e c\alpha^2/2h$	10 973 731.534(13)	m^{-1}	0.0012
23	Rydberg constant in eV	$R_\infty hc/\{e\}$	13.605 698 1(40)	eV	0.30
24	Bohr radius	$a_0 = \alpha/4\pi R_\infty$	$0.529\,177\,249(24) \times 10^{-10}$	m	0.045
25	Quantum of circulation	$h/2m_e$	$3.636\,948\,07(33) \times 10^{-4}$	$m^2\,s^{-1}$	0.089
26	Electron specific charge	$-e/m_e$	$-1.758\,819\,62(53) \times 10^{11}$	$C\,kg^{-1}$	0.30
27	Electron Compton wavelength	$\lambda_C = h/m_e c$	$2.426\,310\,58(22) \times 10^{-12}$	m	0.089
28	Electron classical radius	$r_e = \alpha^2 a_0$	$2.817\,940\,92(38) \times 10^{-15}$	m	0.13
29	Electron magnetic moment`	μ_e	$928.477\,01(31) \times 10^{-26}$	$J\,T^{-1}$	0.34
30	Electron mag. moment anomaly	$a_e = \mu_e/\mu_B - 1$	$1.159\,652\,193(10) \times 10^{-3}$		0.0086
31	Electron *g*-factor	$g_e = 2(1 + a_e)$	2.002 319 304 386(20)		0.00001
32	Muon mass	m_μ	$1.883\,532\,7(11) \times 10^{-28}$	kg	0.61
33	Muon magnetic moment	μ_μ	$4.490\,451\,4(15) \times 10^{-26}$	$J\,T^{-1}$	0.33
34	Muon mag. moment anomaly	$a_\mu = [\mu_\mu/e\hbar/2m_\mu)] -1$	$1.165\,923\,0(84) \times 10^{-3}$		7.2
35	Muon *g*-factor	$g_\mu = 2(1 + a_\mu)$	2.002 331 846(17)		0.0084
36	Proton magnetic moment	μ_p	$1.410\,607\,61(47) \times 10^{-26}$	$J\,T^{-1}$	0.34
37	Proton gyromagnetic ratio	γ_p	$26\,752.212\,8(81) \times 10^4$	$T^{-1}\,s^{-1}$	0.30
38	Neutron magnetic moment	μ_n	$0.966\,237\,07(40) \times 10^{-26}$	$J\,T^{-1}$	0.41
39	Stefan-Boltzmann constant	$\sigma = (\pi^2/60)k^4/\hbar^3 c^2$	$5.670\,51(19) \times 10^{-8}$	$W\,m^{-2}\,K^{-4}$	34
40	First radiation constant	$c_1 = 2\pi hc^2$	$3.741\,774\,9(22) \times 10^{-16}$	$W\,m^2$	0.60
41	Second radiation constant	$c_2 = hc/k$	0.014 387 69(12)	m K	8.4
42	Electron volt	$eV = (e/C)J = \{e\}J$	$1.602\,177\,33(49) \times 10^{-19}$	J	0.30
43	Atomic mass unit	u	$1.660\,540\,2(10) \times 10^{-27}$	kg	0.59
44	Standard atmosphere	atm	101 325	Pa	exact
45	Standard acceleration of gravity	g_n	9.806 65	$m\,s^{-2}$	exact

Notation : $1.602\,177\,33(49) \times 10^{-19}$ C means $(1.602\,177\,33 \pm (0.000\,000\,49) \times 10^{-19}$ C

$C = A\,s$ $F = (C/V) = m^{-2}\,kg^{-1}\,s^4\,A^2$ $Pa = N\,m^{-2} = m^{-1}\,kg\,s - 2$ $T = kg\,s^{-2}\,A^{-1}$ $W = J\,s^{-1} = m^2\,kg\,s^{-3}$

$Wb = V\,s = m^2\,kg\,s^{-2}\,A^{-1}$ $Fm^{-1} = (C/V)\,m^{-1} = m^{-3}\,kg^{-1}\,s^4\,A^2$ $T\,s = kg\,s^{-1}\,A^{-1}$ $J\,T^{-1} = m^2\,A$

Prism Spectrograph A.A. Ångström (1853)



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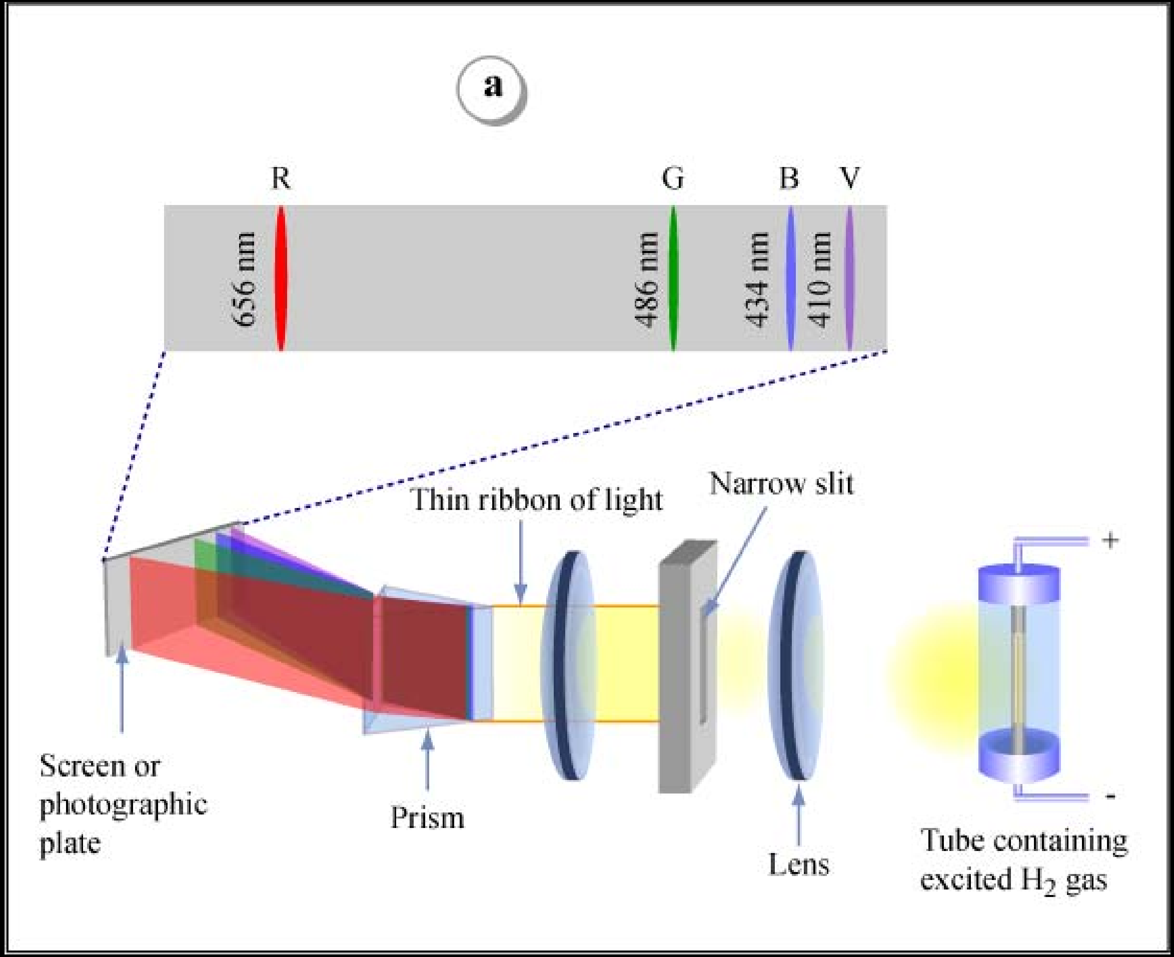
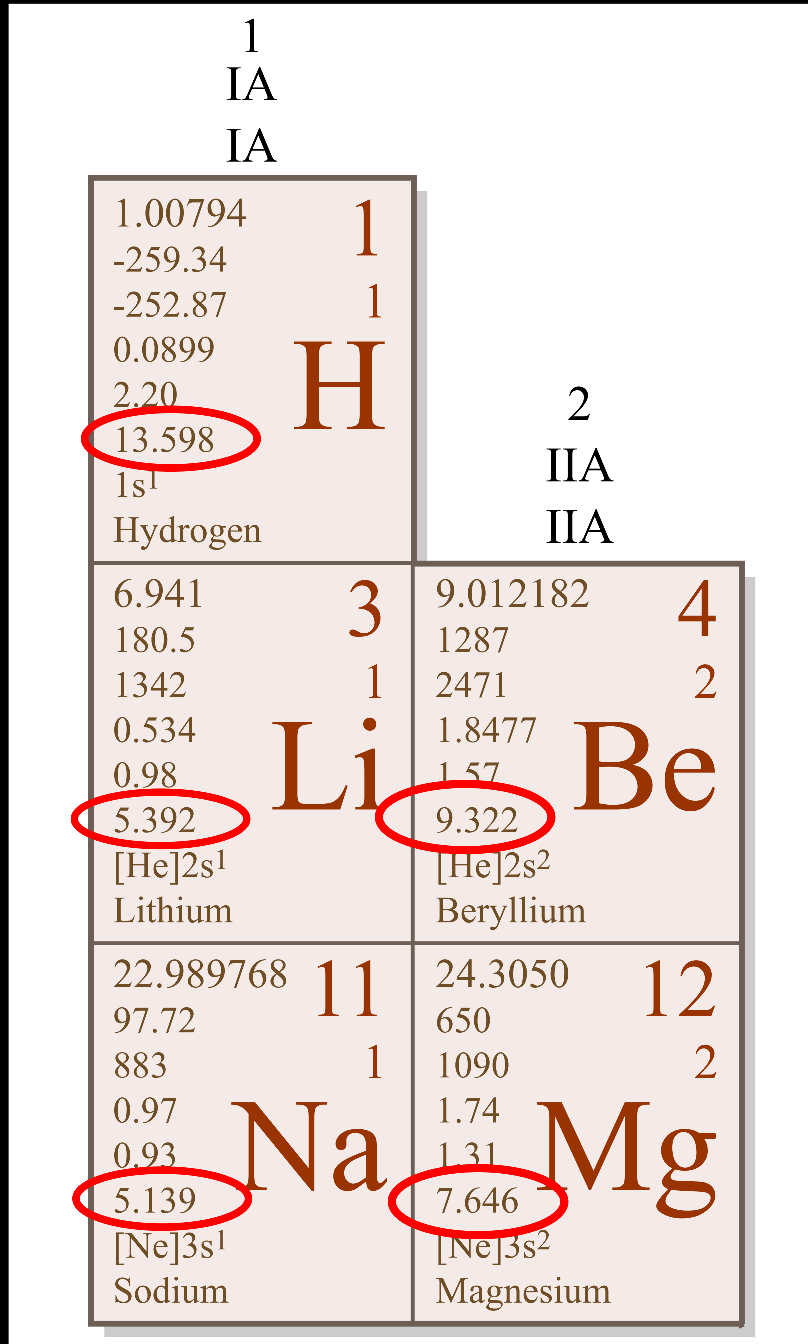

a
R
G
B
V
656 nm
486 nm
434 nm
410 nm
Thin ribbon of light
Narrow slit
+
-
Screen or photographic plate
Prism
Lens
Tube containing excited H_2 gas



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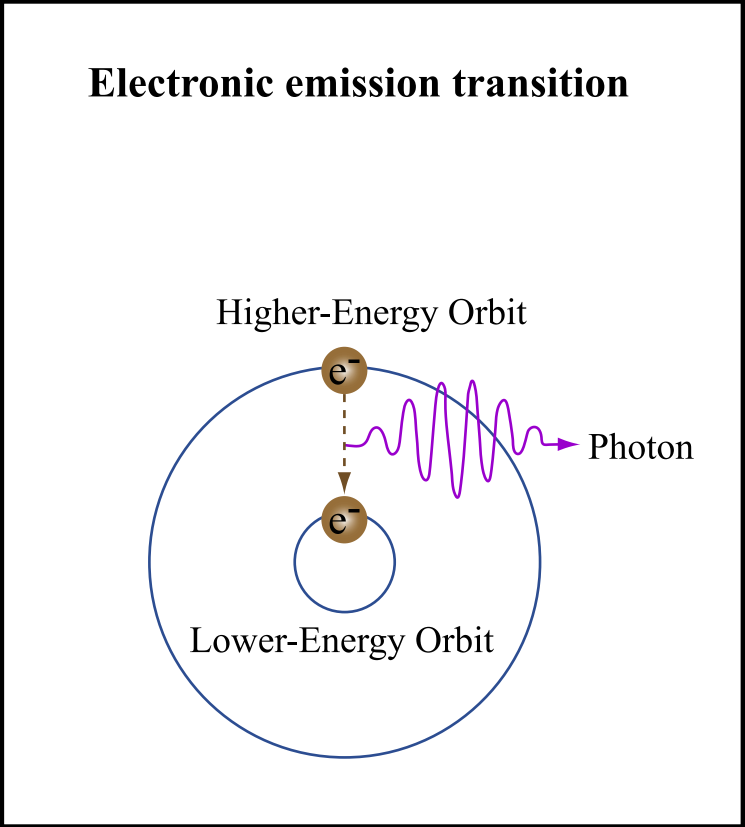
C = A s   F = (C/V) = m^{-2} kg^{-1} s^4 A^2 Pa = N m^{-2} = m^{-1} kg s – 2   T = kg s^{-2} A^{-1} W = J s^{-1} = m^2 kg s^{-3}

Wb = V s = m^2 kg s^{-2} A^{-1} Fm^{-1} = (C/V) m^{-1} = m^{-3} kg^{-1} s^4 A^2 T s = kg s^{-1} A^{-1} J T^{-1} = m^2 A


Electronic emission transition
Higher-Energy Orbit
e-
e-
Photon
Lower-Energy Orbit

Bohr Postulates for the Hydrogen Atom

1. Rutherford atom is correct
2. Classical EM theory not applicable to orbiting e^-
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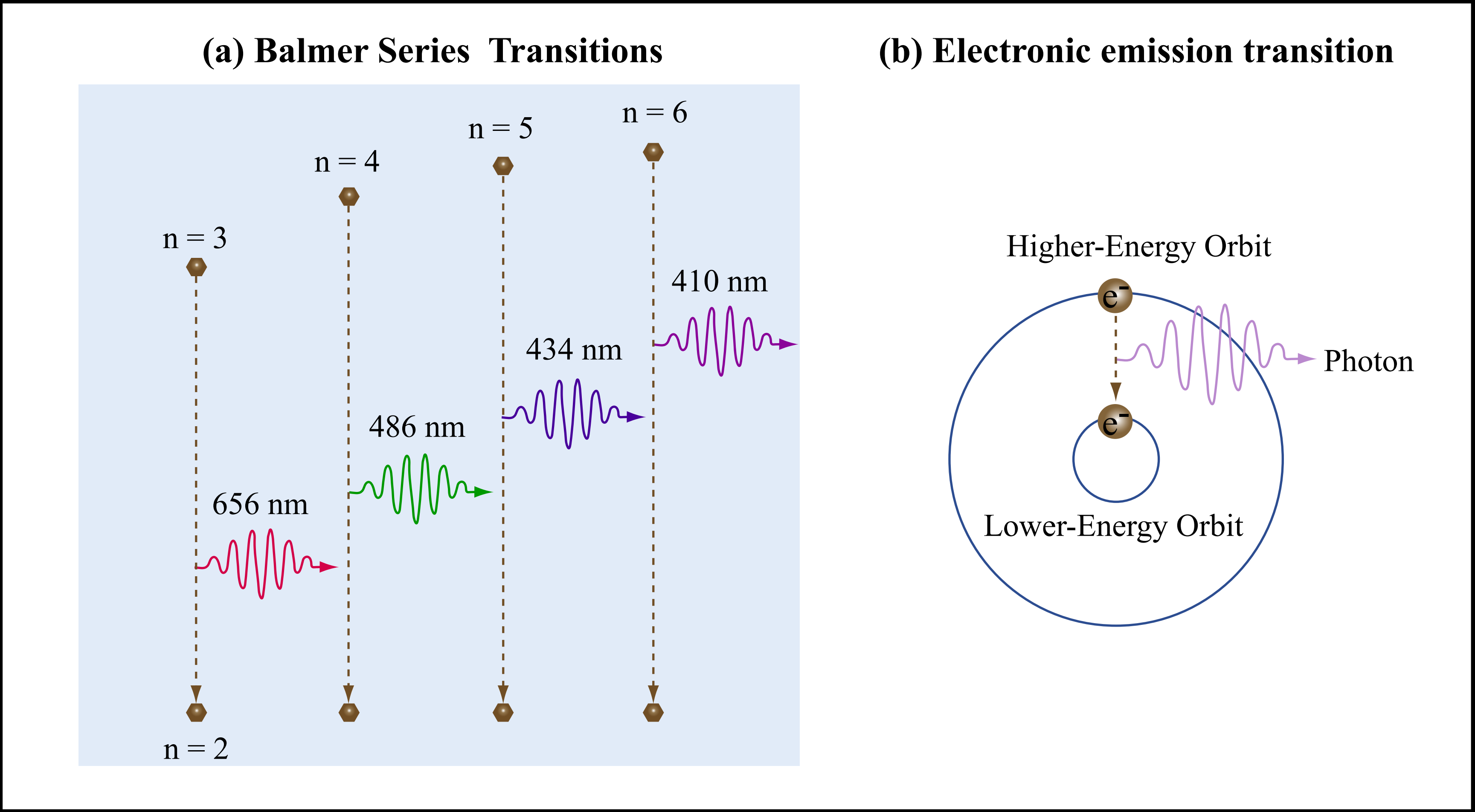

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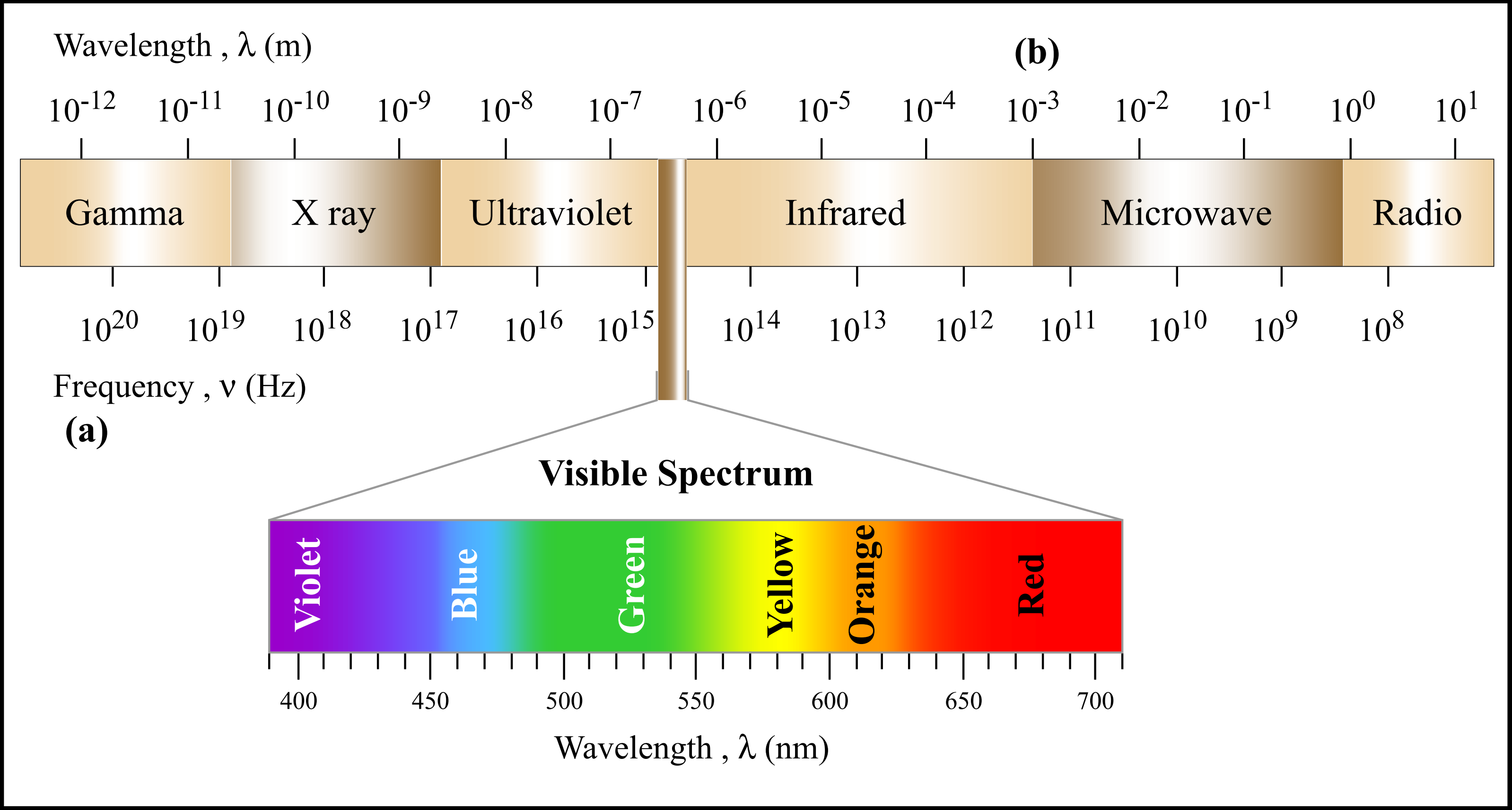
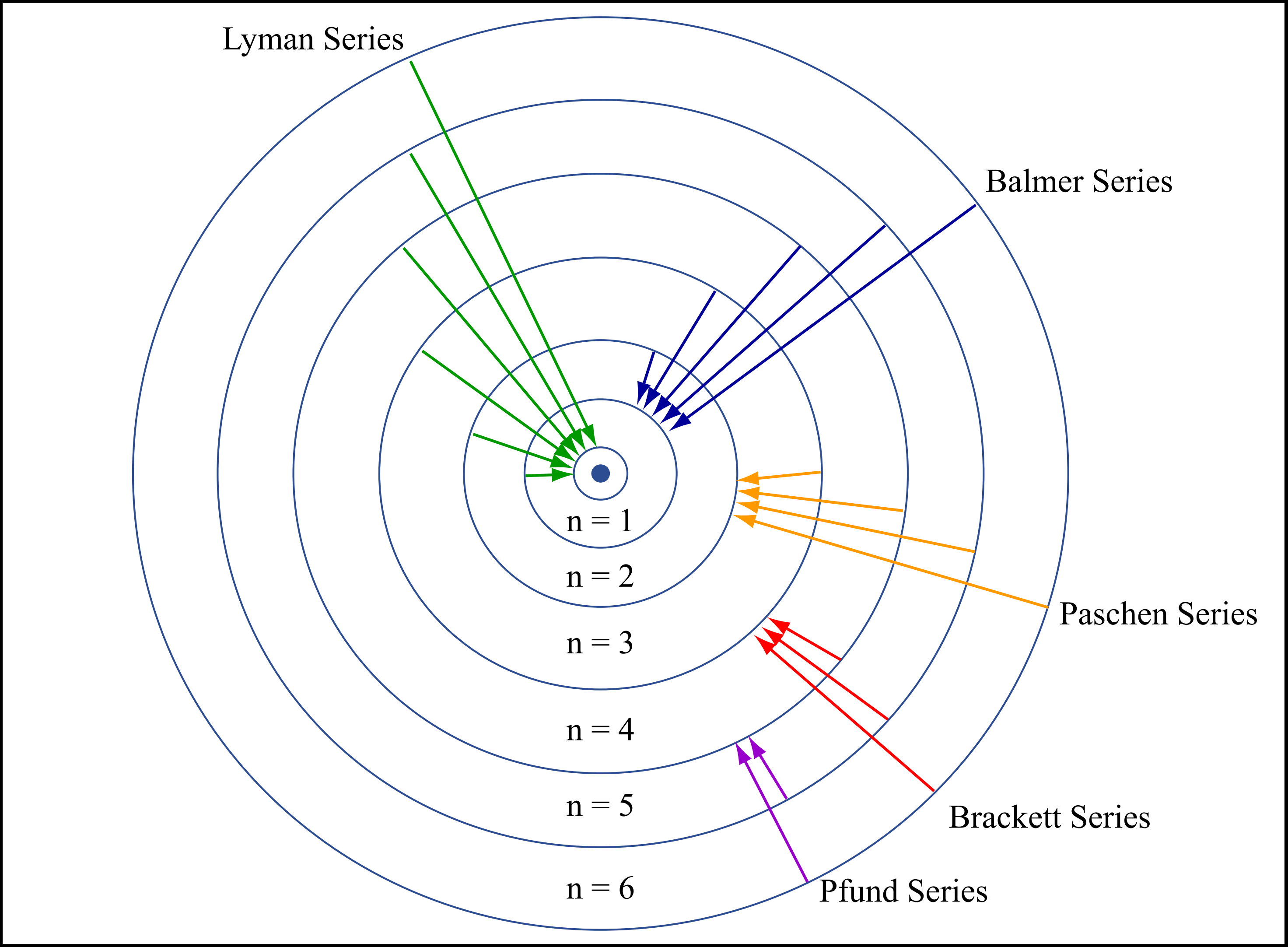


Wavelength , λ (m)
(b)
10-12 10-11 10-10 10-9 10-8 10-7 10-6 10-5 10-4 10-3 10-2 10-1 100 101
Gamma
X ray
Ultraviolet
Infrared
Microwave
Radio
1020 1019 1018 1017 1016 1015 1014 1013 1012 1011 1010 109 108
Frequency , ν (Hz)
(a)
Visible Spectrum
Violet
Blue
Green
Yellow
Orange
Red
400 450 500 550 600 650 700
Wavelength , λ (nm)


Lyman Series
Balmer Series
Paschen Series
Brackett Series
Pfund Series
n = 1
n = 2
n = 3
n = 4
n = 5
n = 6

Cecilia Payne (1900-1979)

1st woman graduate student in Astronomy at Harvard

1st Ph.D. in Astronomy at Harvard

1st woman to receive tenure at Harvard

1st woman to chair the Faculty of Arts and Sciences at Harvard

awarded tenure in 1938 but denied a professorship for 18 years

forced to recant her findings that the sun is not dominantly iron but rather hydrogen

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h y d ro g en

lines characteristic of atomic H

"The enormous abundance [of hydrogen]…
is almost certainly not real."

- Cecilia Payne, Ph.D. Thesis, Harvard College

"The enormous abundance [of hydrogen]…
is almost certainly not real."

- Cecilia Payne, Ph.D. Thesis, Harvard College

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