Centro de Energia Nuclear na Agricultura

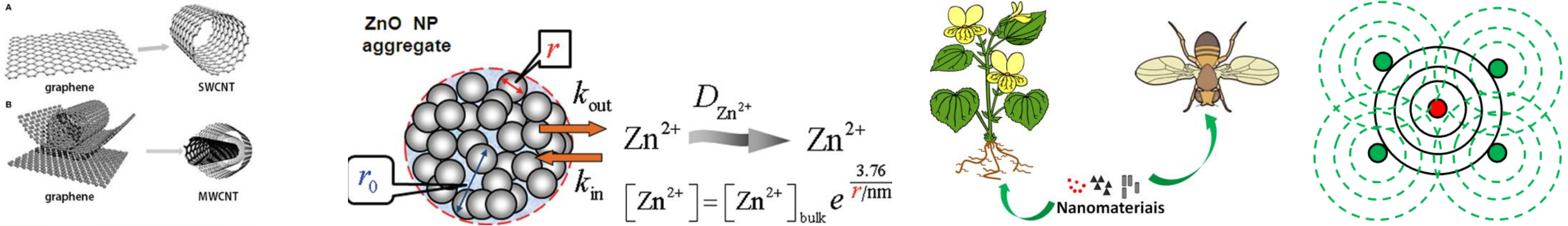
Campus ´´Luiz de Queiroz´´

Interaction between radiation & matter

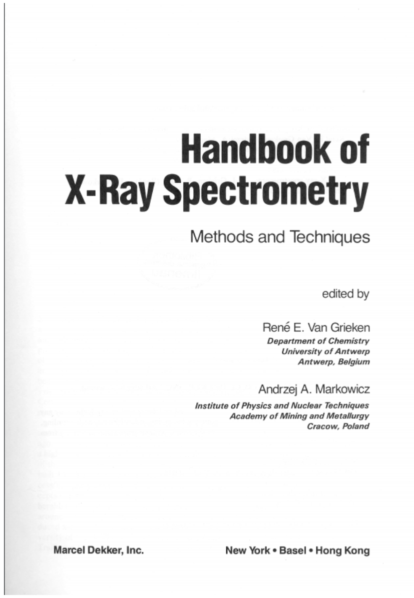
Prof. Hudson W.P. Carvalho

Applied X-ray Spectroscopy

Laboratory of Nuclear Instrumentation



Bibliography



Handbook of
X-Ray Spectrometry

Methods and Techniques

edited by

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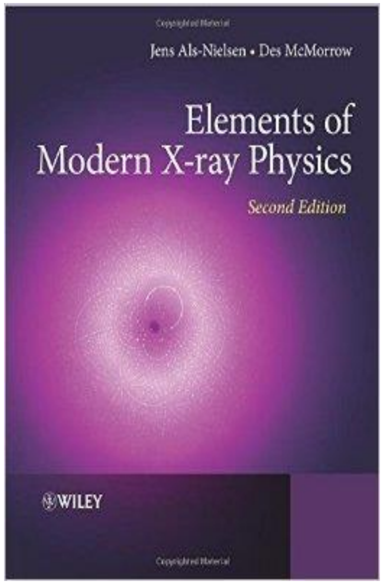
Chapter 1



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Elements of
Modern X-ray Physics

Second Edition

WILEY

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Chapter 1

Syllabus for today

- ☐ Types of interaction
- ☐ Cross sections

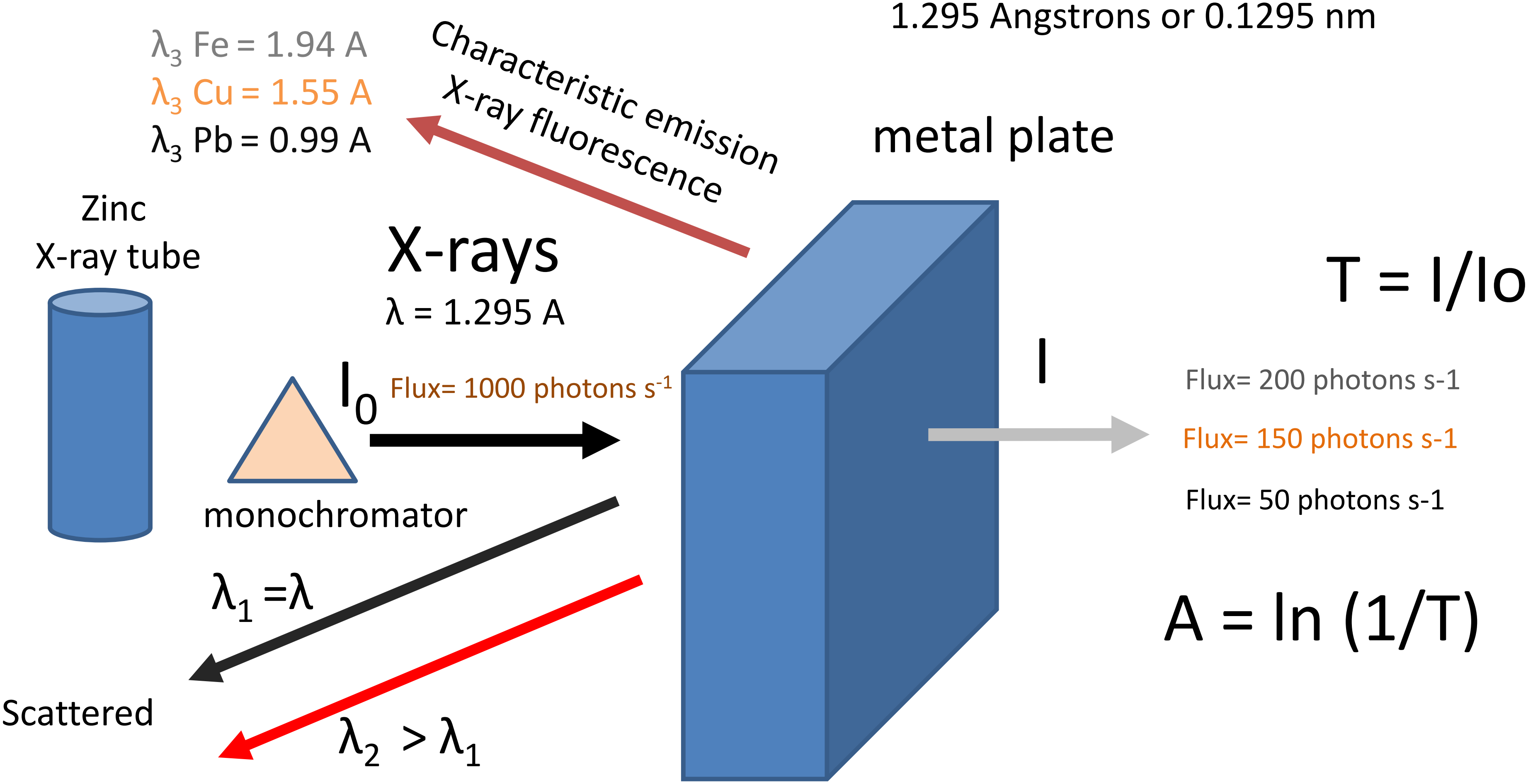
X-ray regime

- ☐ X-ray Absorption and relaxation processes
- ☐ Elastic X-ray scattering
- ☐ Inelastic X-ray scattering

5.1 Types of interaction

Monochromatic = only one wavelenght

X-ray zinc tube =
1.295 Angstrons or 0.1295 nm



λ_3 Fe = 1.94 A
λ_3 Cu = 1.55 A
λ_3 Pb = 0.99 A

Characteristic emission
X-ray fluorescence

metal plate

Zinc
X-ray tube

X-rays
λ = 1.295 A

$T = I/Io$

I_0 Flux= 1000 photons s^{-1}

monochromator

I

Flux= 200 photons s-1

Flux= 150 photons s-1

Flux= 50 photons s-1

$\lambda_1 = \lambda$

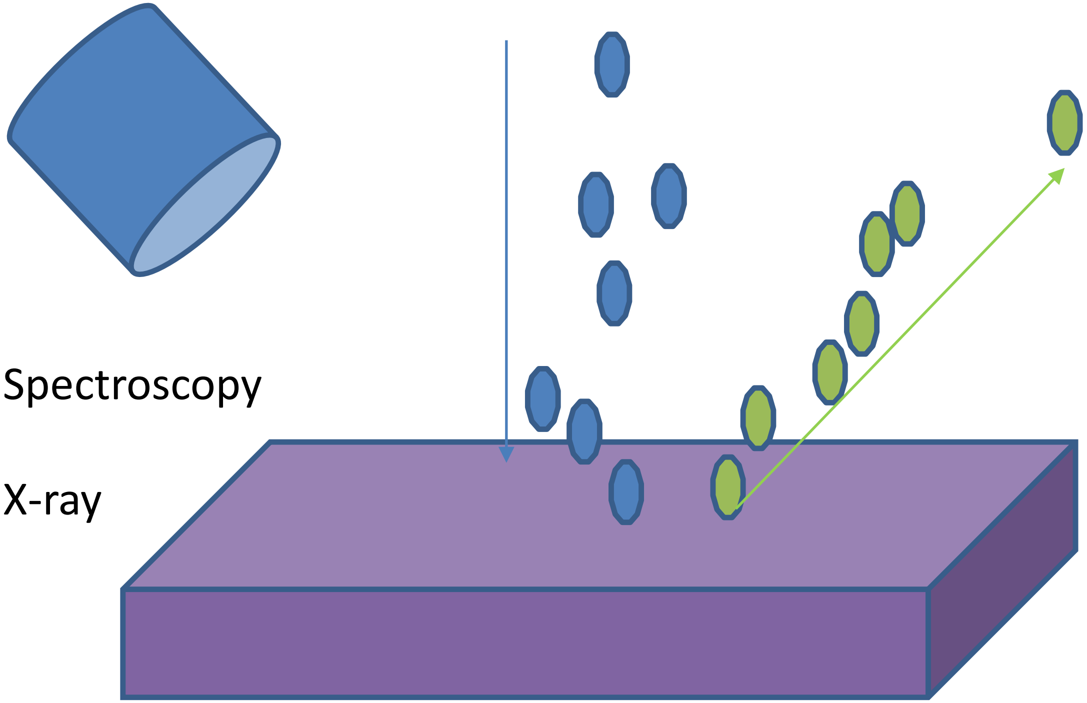
Scattered

$\lambda_2 > \lambda_1$

$A = \ln(1/T)$

λ_1= 1.295 A – Ellastic Scattering or Thomson Scattering

λ_2= 1.395 A – Inellastic Scattering or Compton Scattering



EDS = EDX
Energy Dispersive Spectroscopy

Energy Dispersive X-ray

It detects X-ray Fluorescence
It detects all elements above C, the limit of detection for EDS is ca. 1 wt%

$E = hv$

$E = (hc) / \lambda$

E- energy (eV)

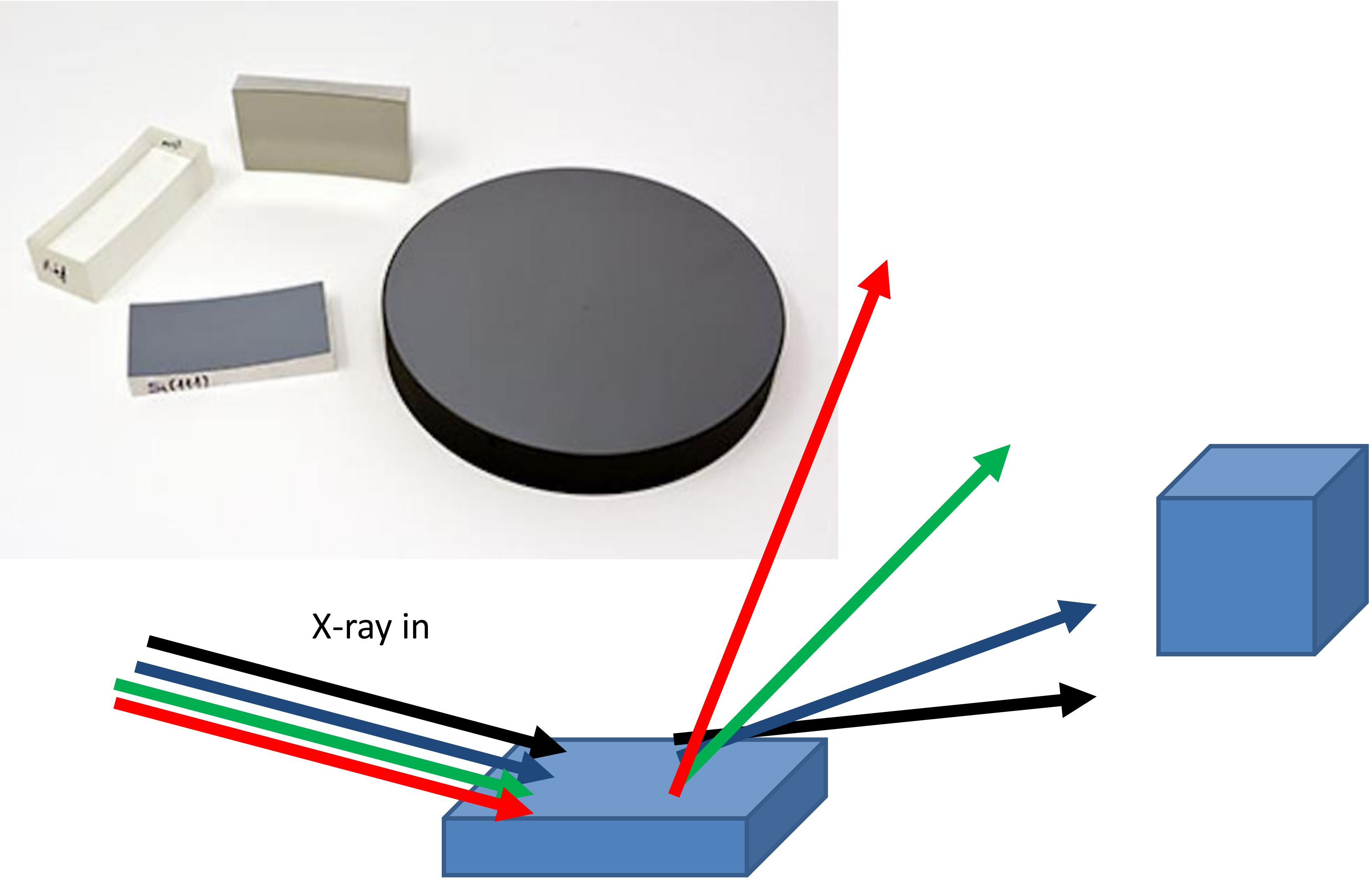
h – Plank's constant (eV)

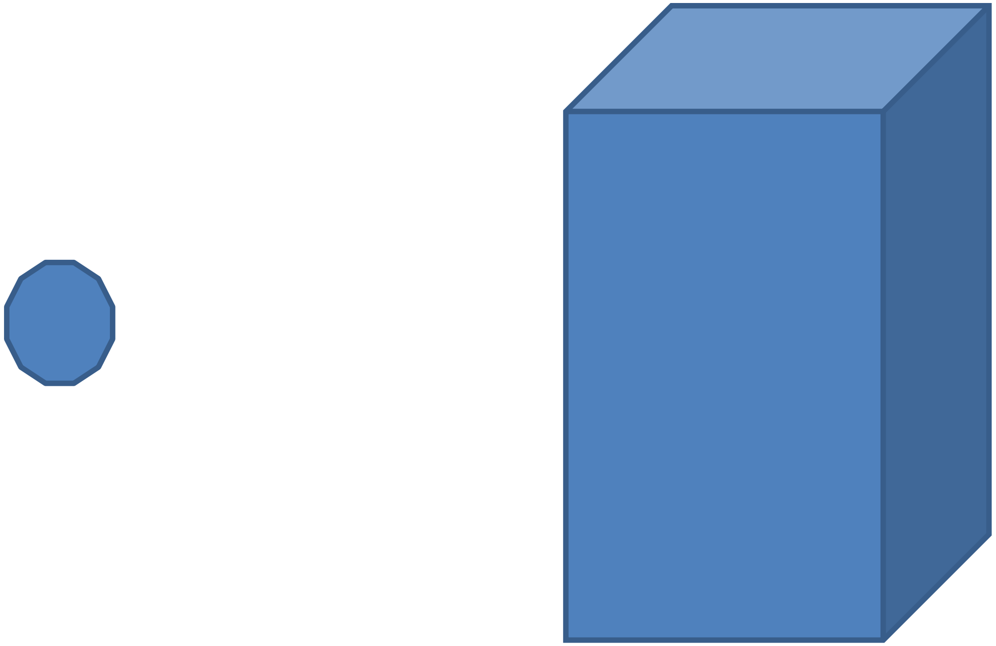
v – frequency

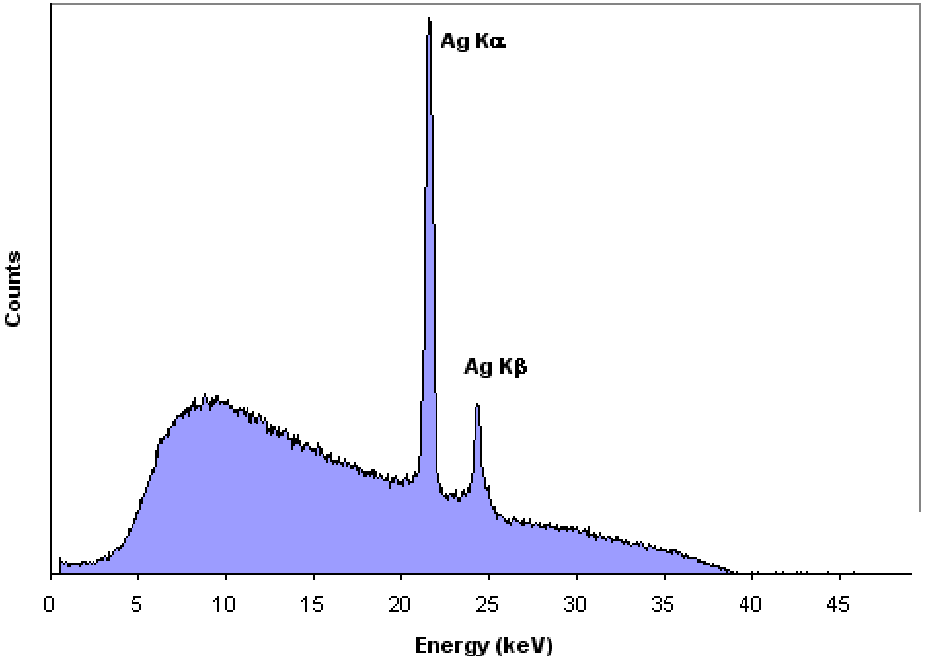
$V = c/\lambda$

c- speed of light

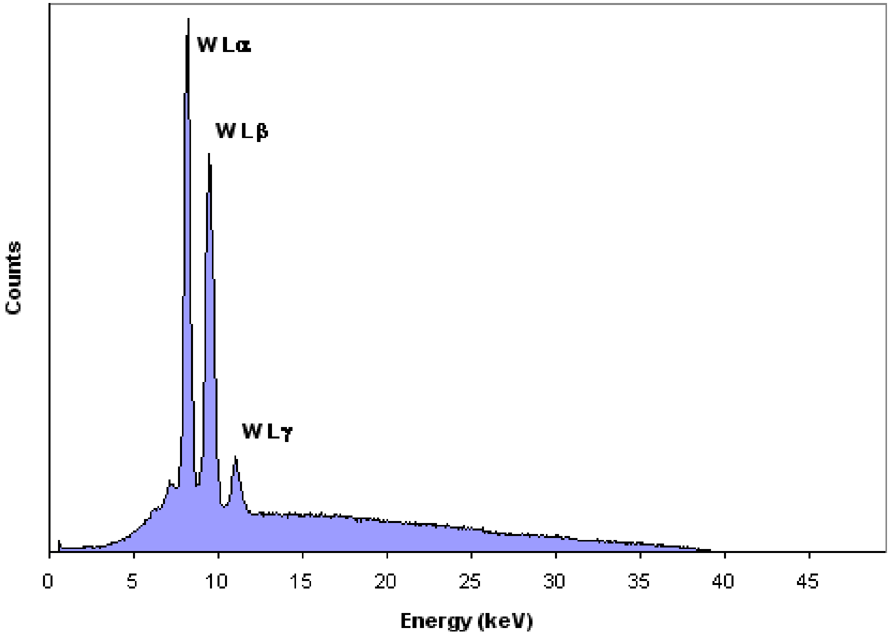
λ - wavelenght


X-ray in

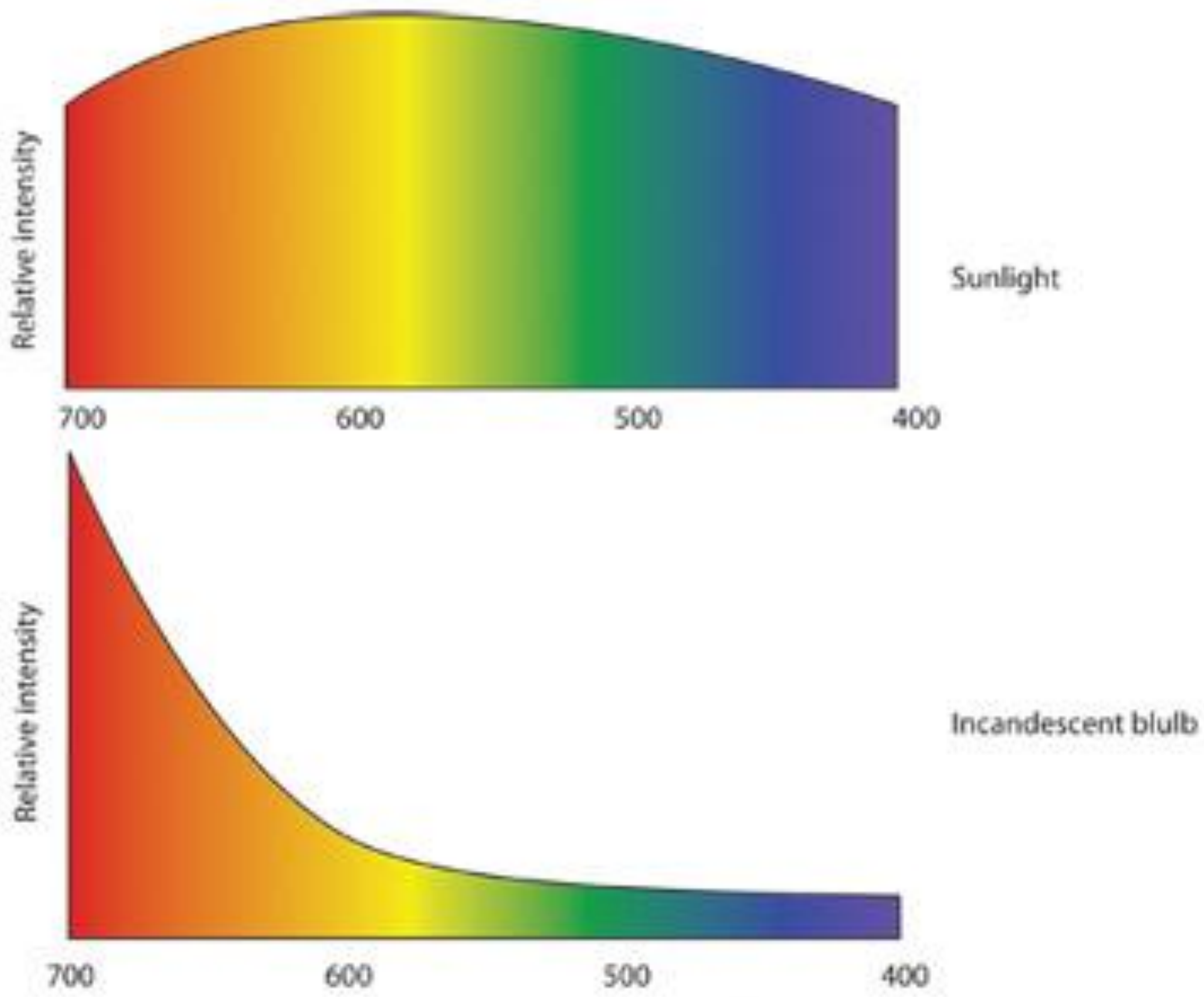




Mini-X Output X-Ray Spectrum: Ag Target @ 40 kV



Mini-X Output X-Ray Spectrum: W Target @ 40 kV


Relative intensity
Sunlight
700
600
500
400
Relative intensity
Incandescent blulb
700
600
500
400

nm

Types of interaction

What happens when one shines matter with X-rays?

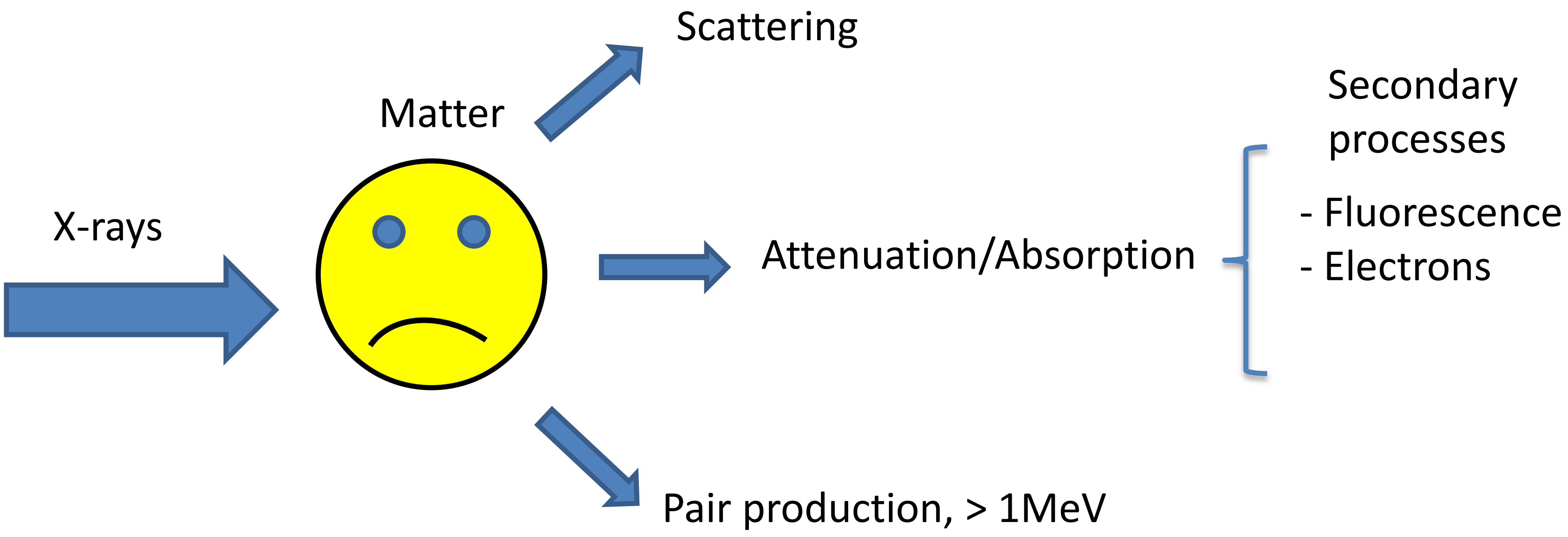
´It was known that the radiation leaving an X-ray tube was heterogeneous and dependent on the material of the anti-cathode….
When such a homogeneous X-ray beam hits a plate of some element three kinds of *secondary* radiations are emitted….
by Manne Siegbahn

- Siegbahn spectrometer, before 1920.

Extract from *50 Years of X-ray Diffraction*, edited by P. P. Ewald

Types of interaction

- What happens when one shines matter with X-rays?



X-rays

Matter

Scattering

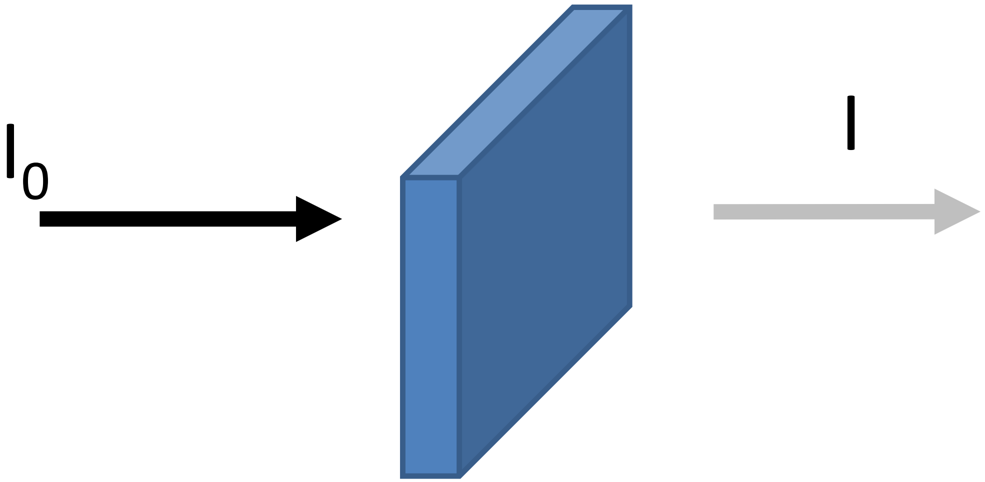
Attenuation/Absorption

Pair production, > 1MeV

Secondary processes

- Fluorescence
- Electrons

Atennuation = Absorption + Ellastic Scattering + Inelastic Scattering



How important are these phenomenon?

τ Photoelectric absorption

σ_{coh} Ellastic scattering

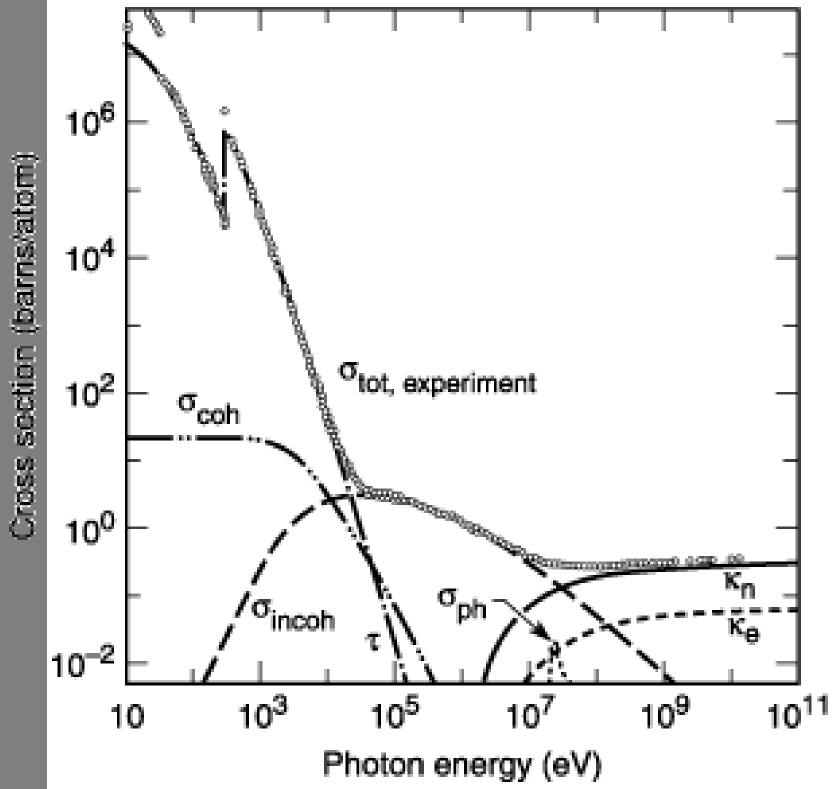
σ_{incoh} Inellastic scattering

κ_e Pair production in electron field

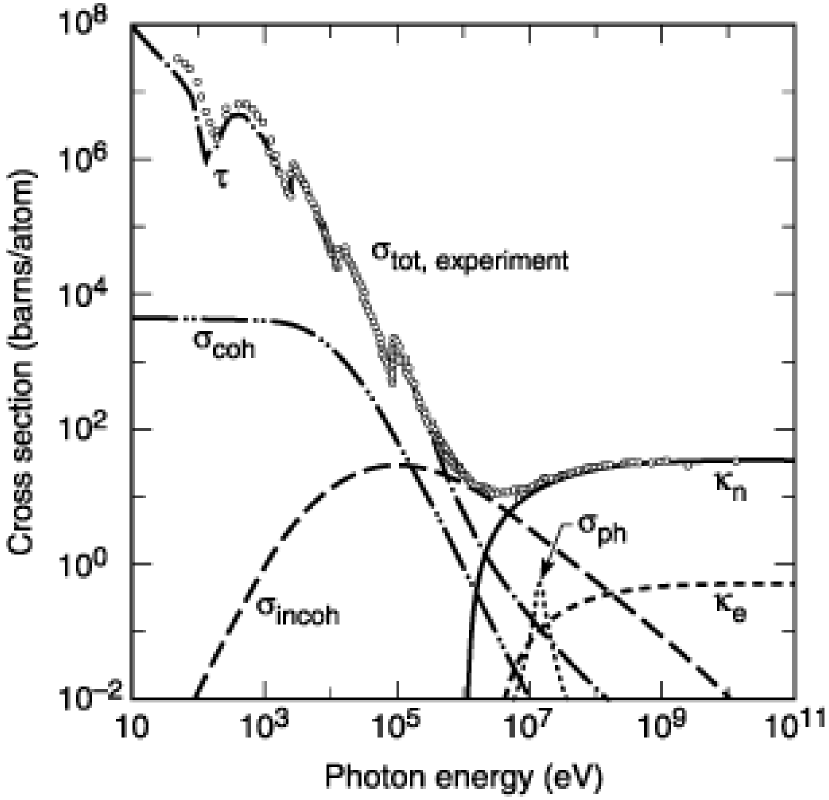
κ_n Pair production in nuclear field

σ_{ph} Photonuclear absoprtion

Carbon

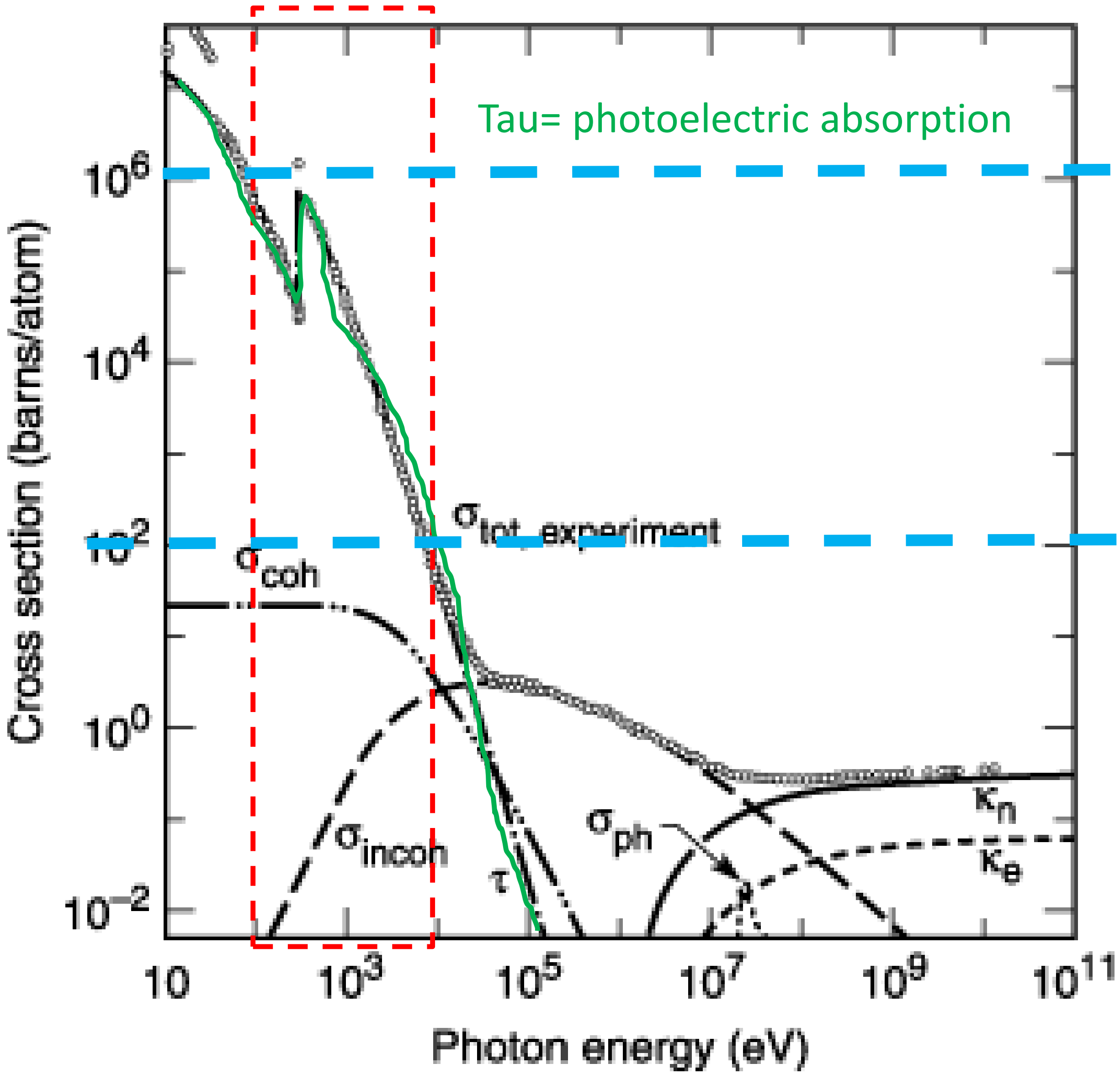


Lead



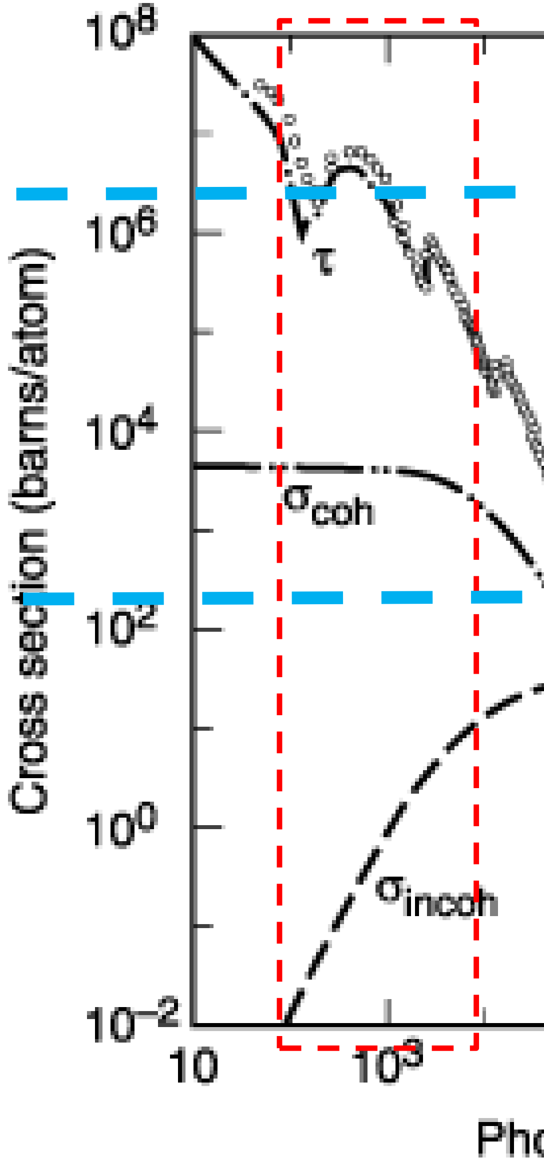
Attenuation

Organic sample



Tau= photoelectric absorption

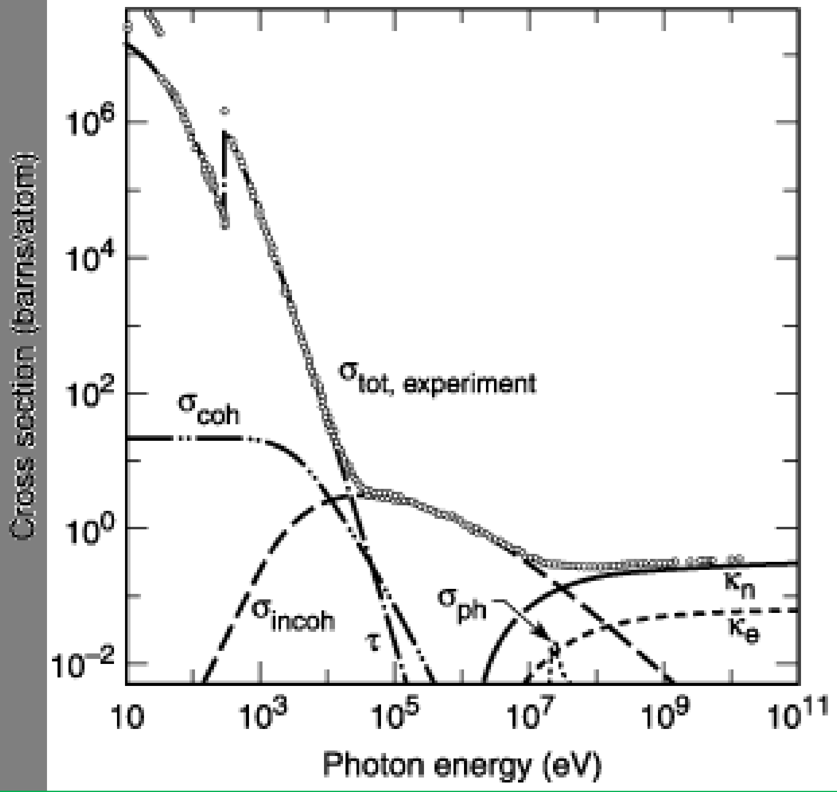
Lead



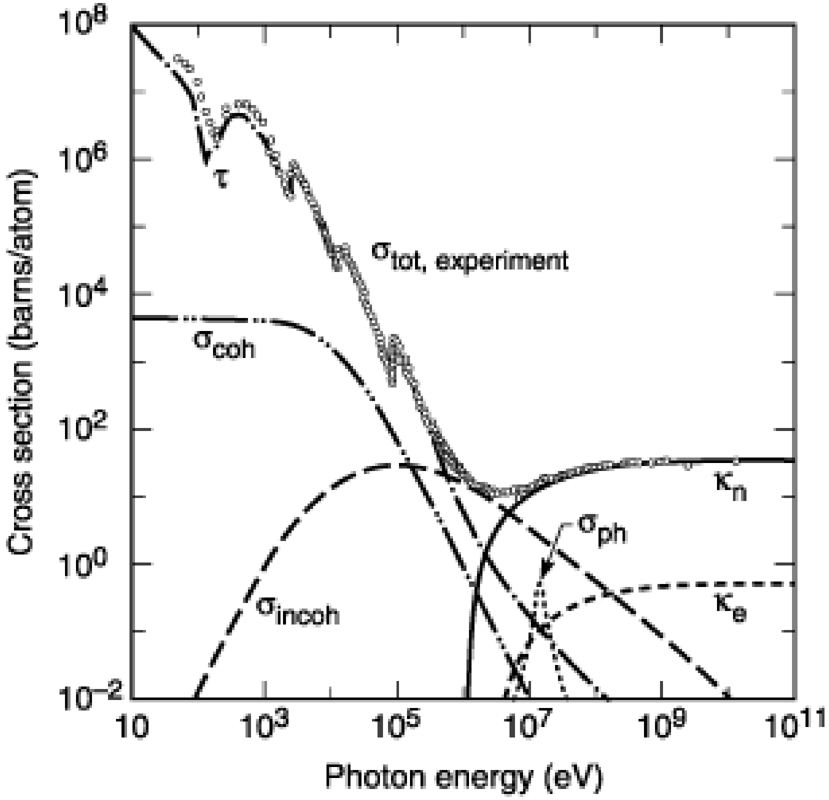
How important are these phenomenon?

- ☐ What singularities one may capture from C and Pb?
- ☐ Why has C only one sharp increase of τ whereas Pb has several?

Carbon



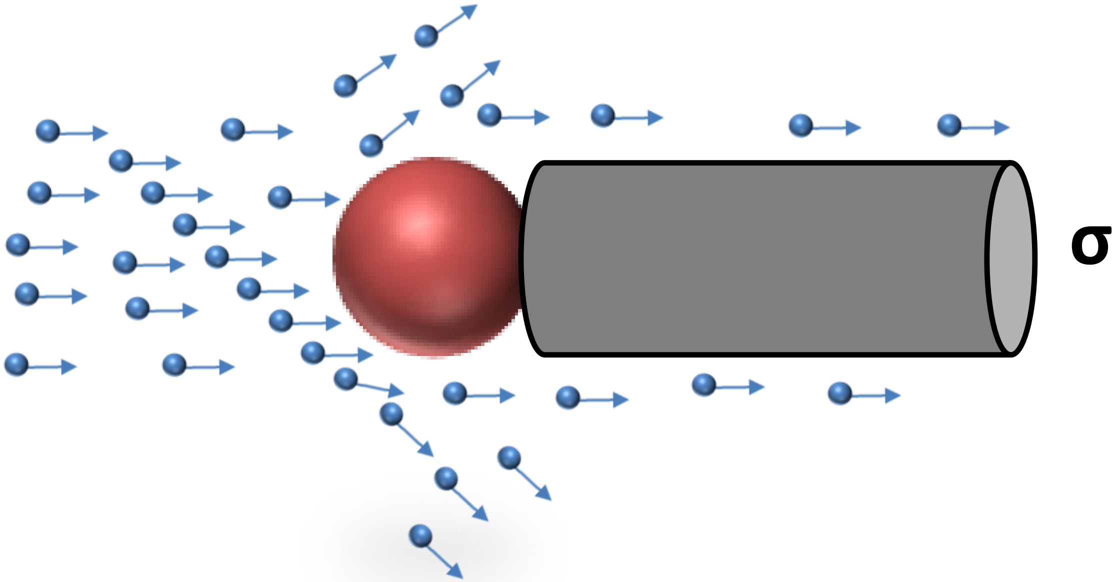
Lead

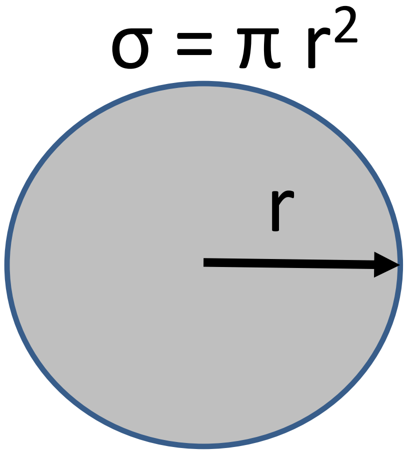


5.2 Cross sections

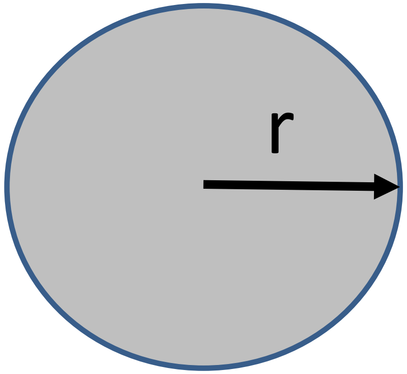
Cross sections

- Is the effective area that express the probability of an scattering event to occur
- The higher the cross section, the higher is the probability
- The cross section is expressed in m^2 or in Barn = 10^{-28} m^2

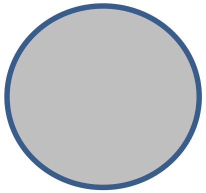




$\sigma = \pi r^2$

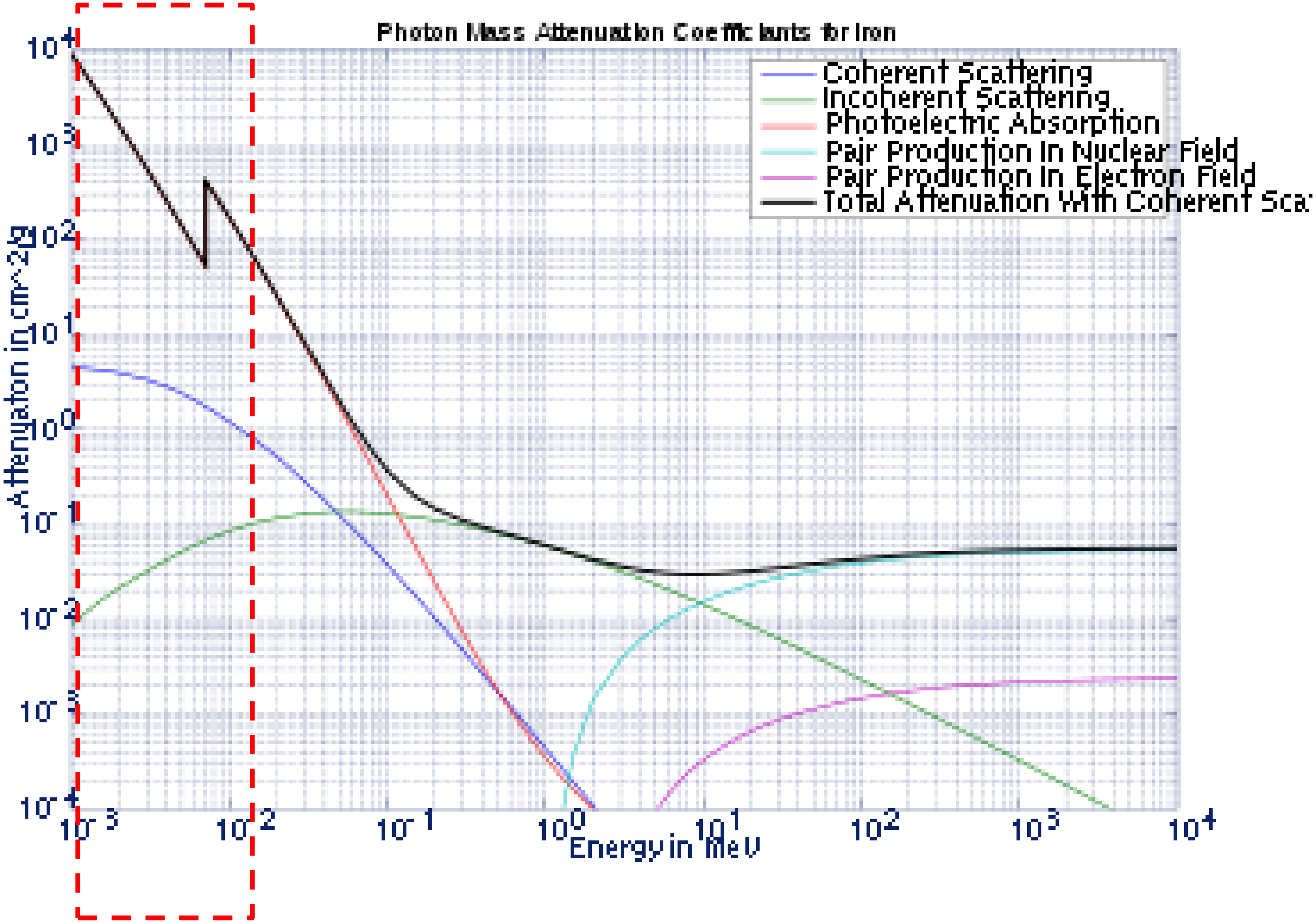


1740 eV
Si K edge



7112 eV
Fe K edge

Cross section for Copper



https://upload.wikimedia.org/wikipedia/commons/thumb/e/ed/Attenuation_Coefficient_Iron.svg/400px-Attenuation_Coefficient_Iron.svg.png

Cross sections and atomic raddii

- Attenuation cross sections represent how ‘large’ is atom from the photon point of view

Atomic raddi in 10^{-12} m

http://images.flatworldknowledge.com/averillfwk/averillfwk-fig07_007.jpg

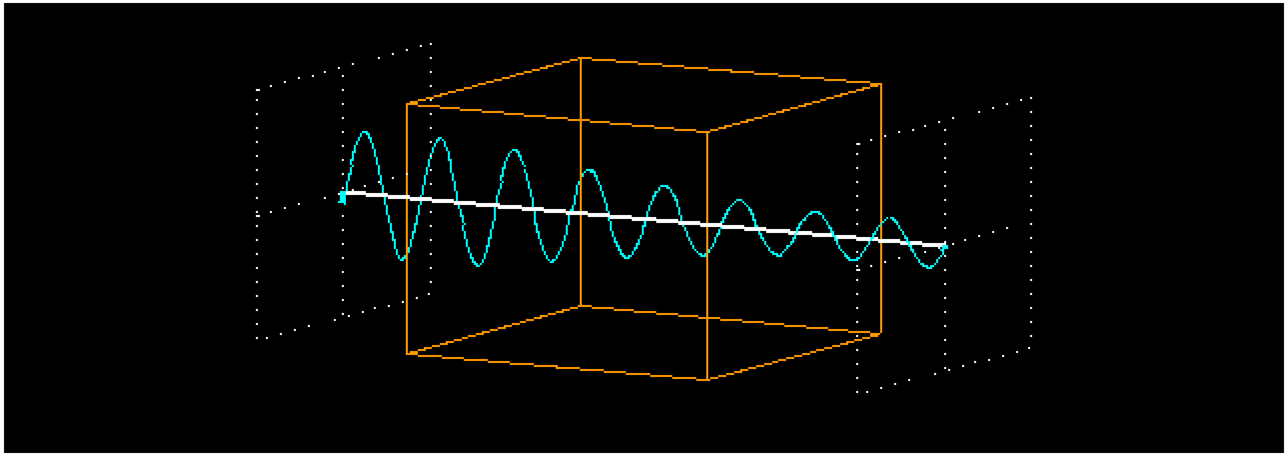
X-ray attenuation image

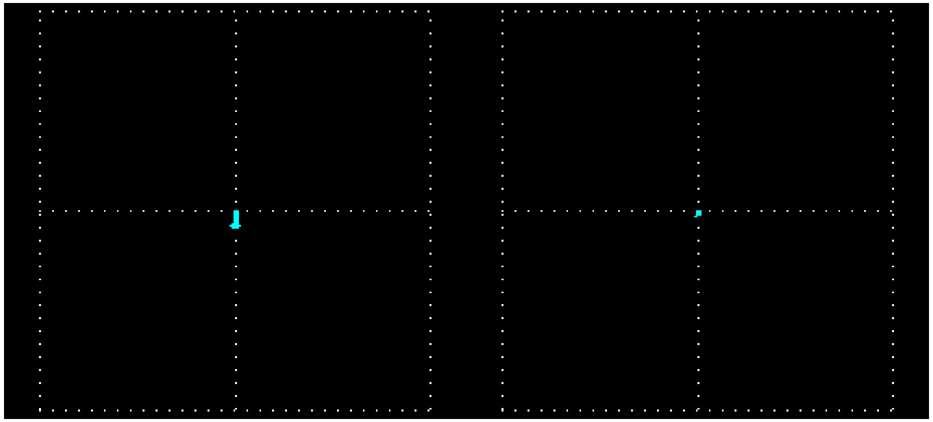
http://www.sbcc.edu/careercenter/images/Radiography%20-%20Hands.jpg

5.3 X-ray photoelectric absorption and relaxation processes

Absorption of a polarized

- ☐ The reduction in the number of photons is represented as a decrease in the amplitude of the wave

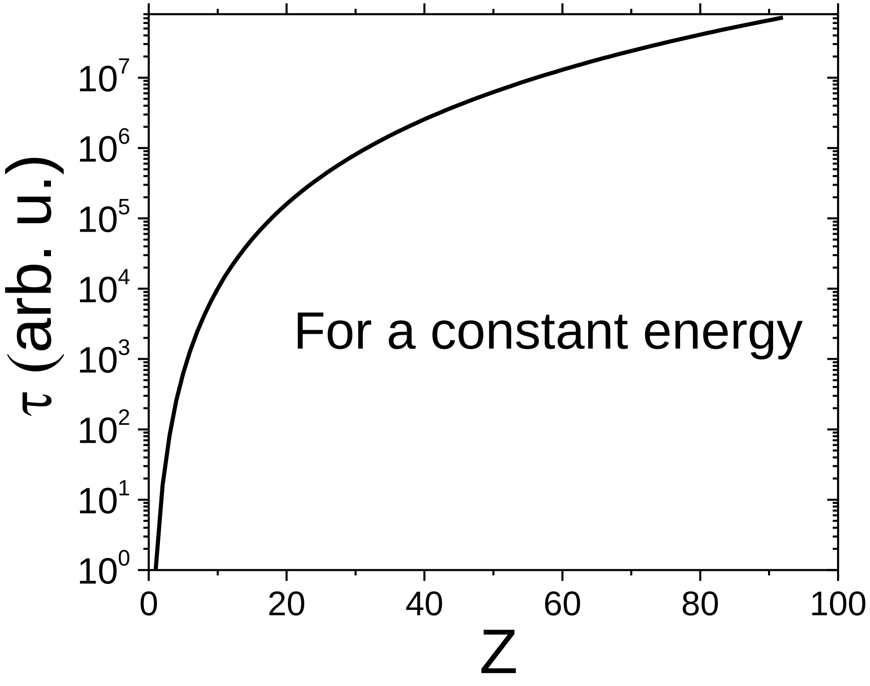


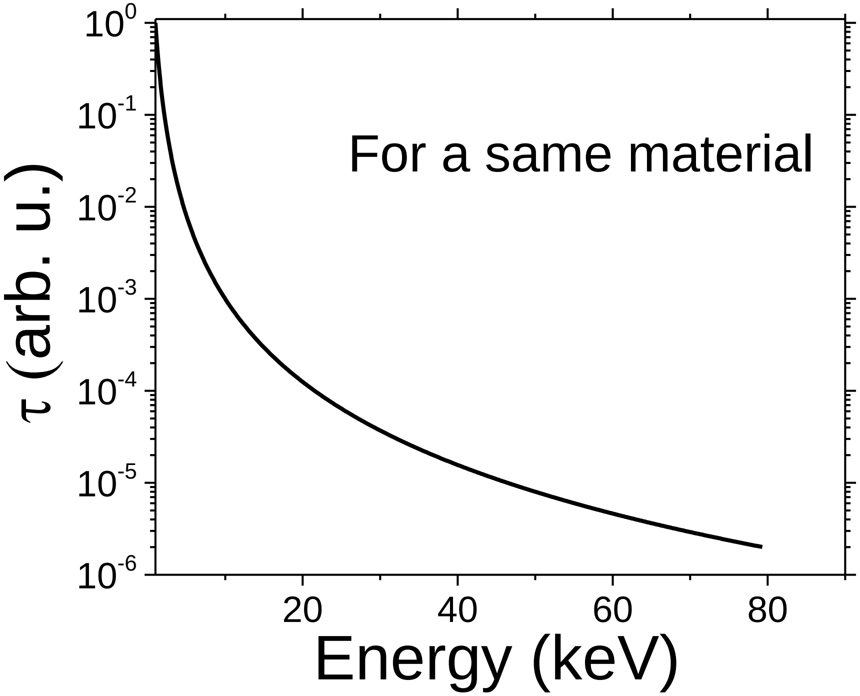


http://cddemo.szialab.org/

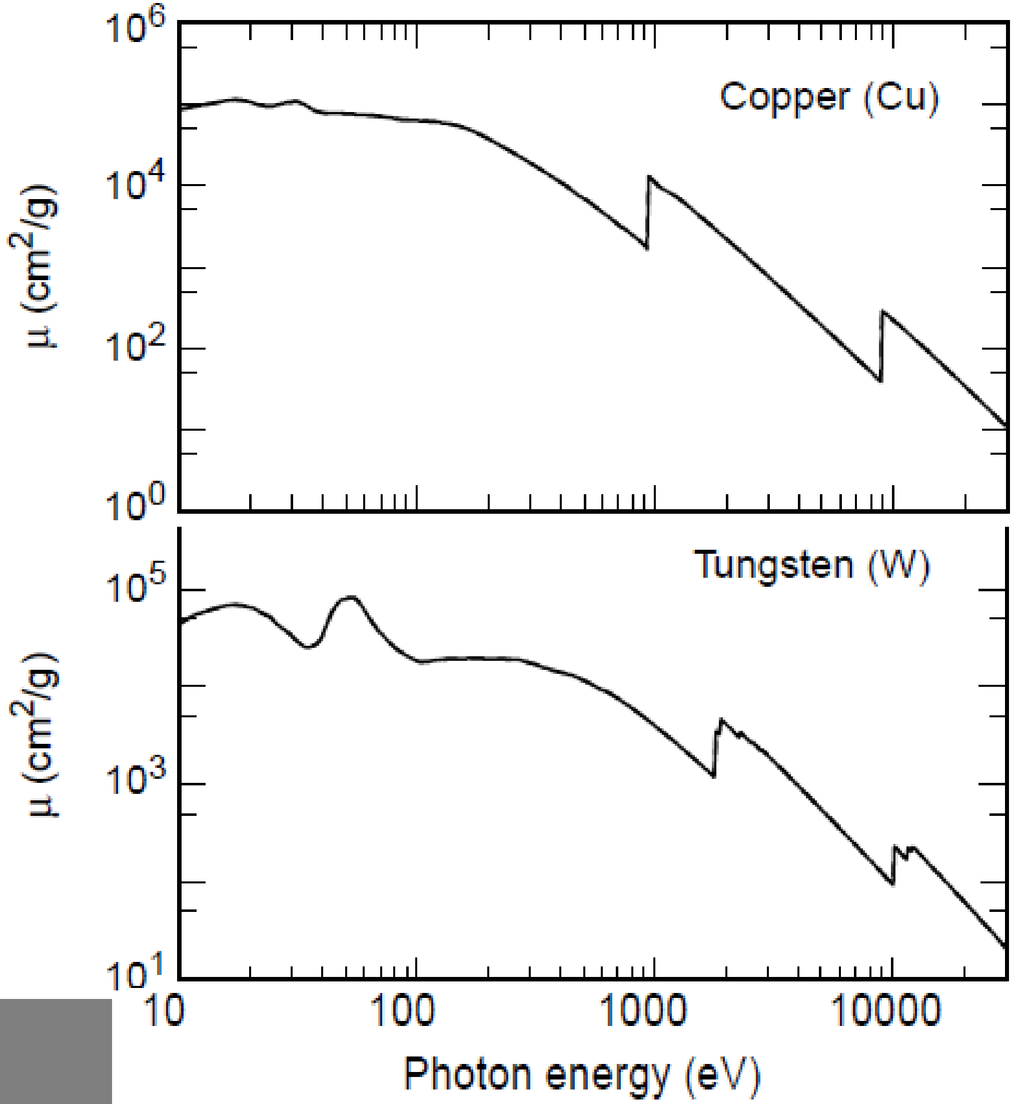
X-ray photoelectron absorption

❑ The photoelectron absorption increases as function of Z and decreases as function of E



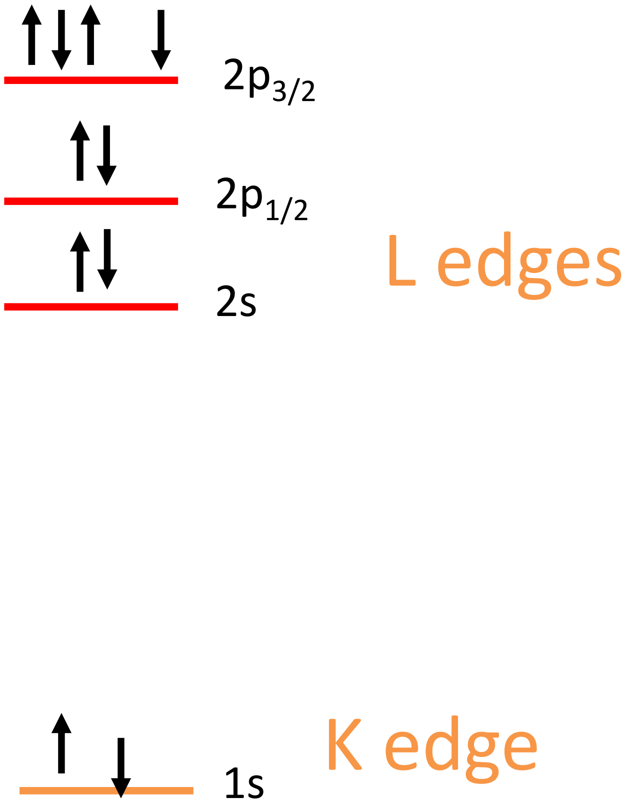


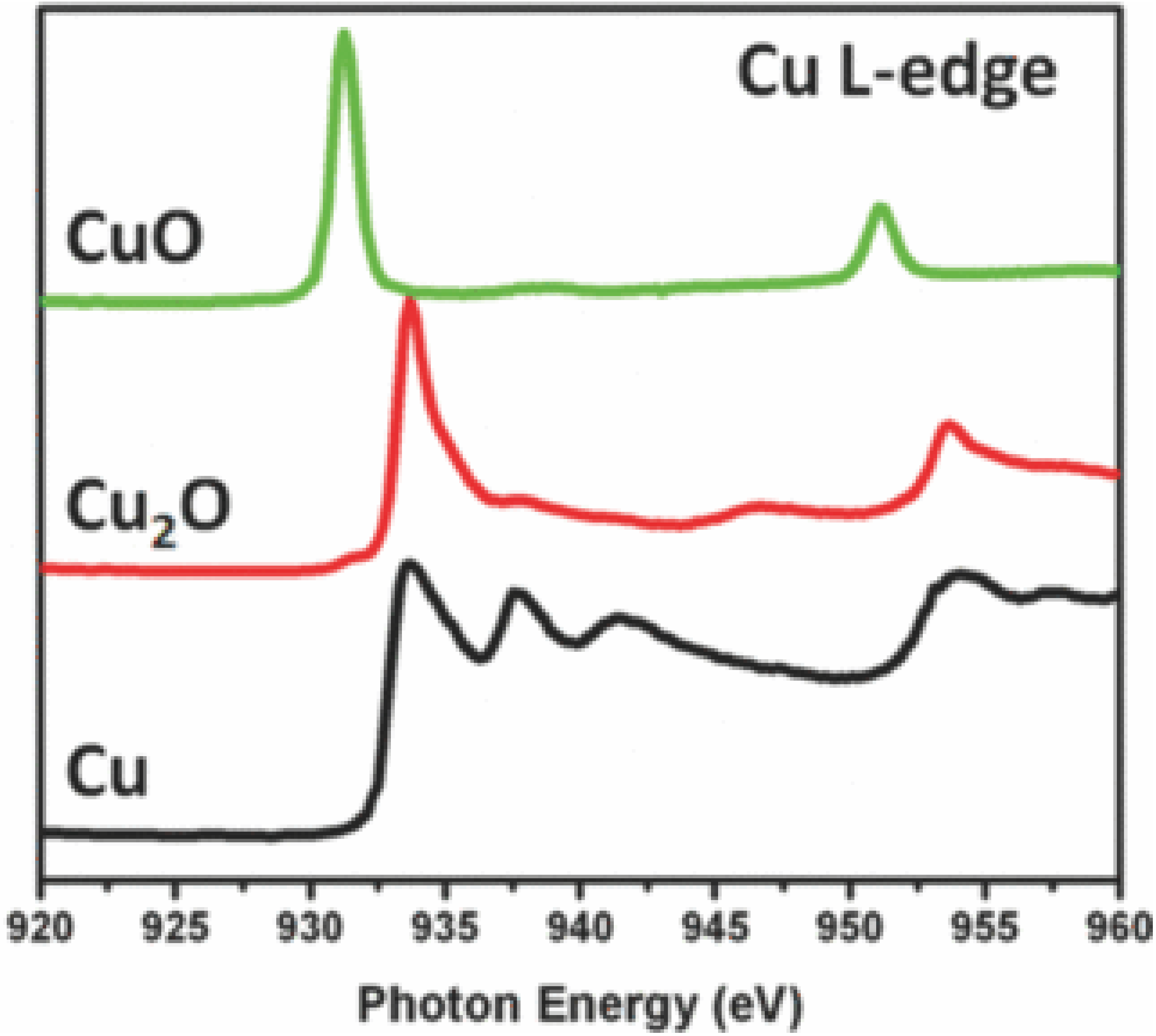
Attenuation cross section discontinuities



- What are these sharp increases in μ?

Cu

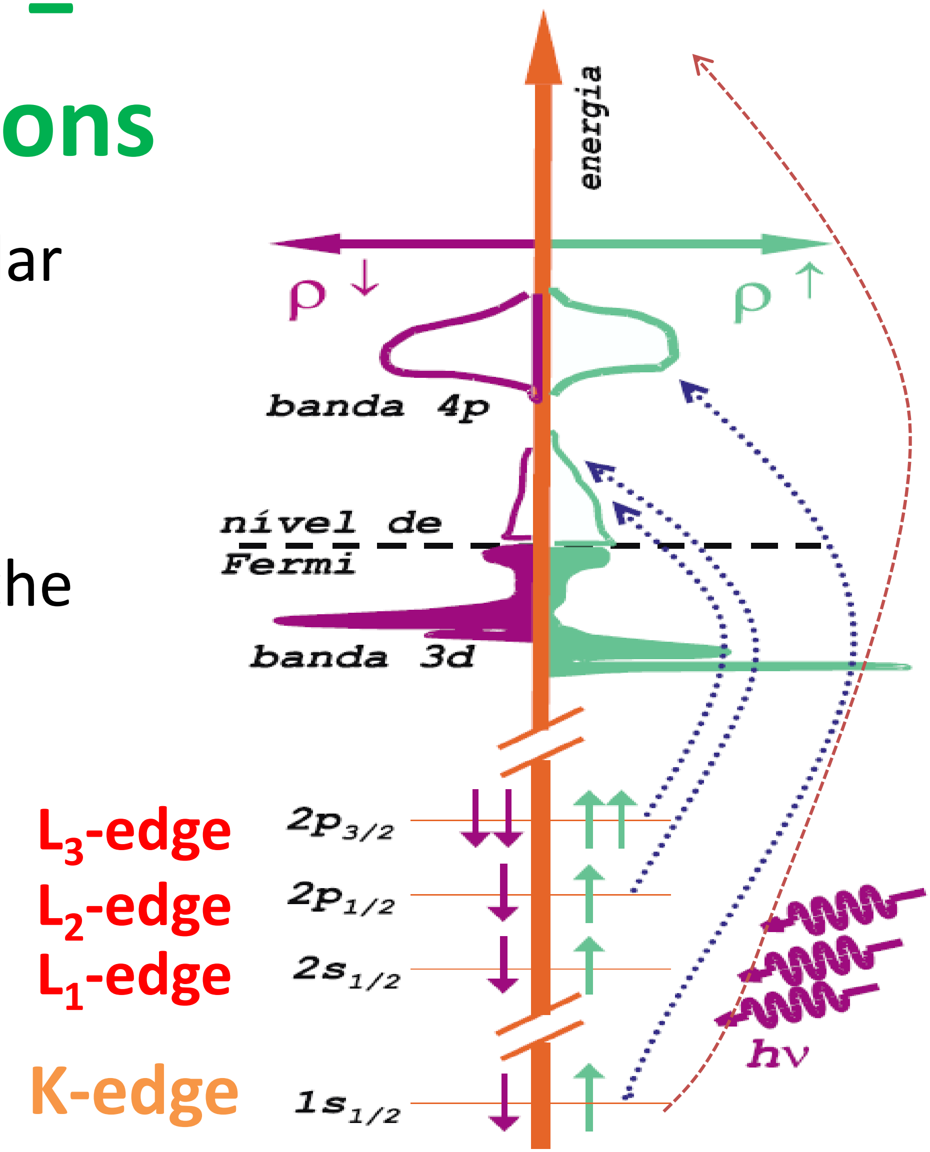



Cu L-edge
CuO
Cu_2O
Cu
920
925
930
935
940
945
950
955
960
Photon Energy (eV)

Absorption edges = Electronic transitions

- The orbitals have particular energies

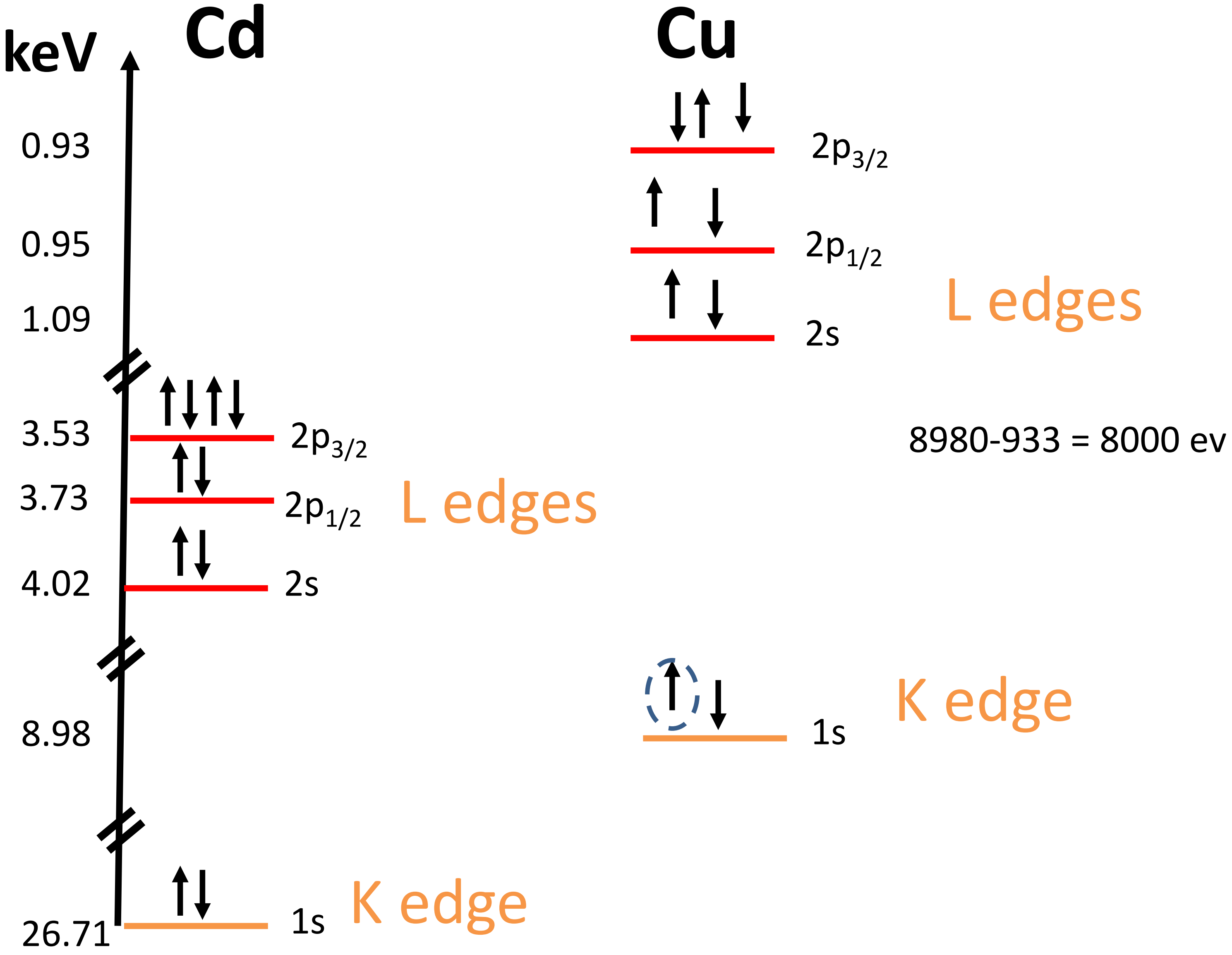
- When the photon has energy slightly higher than the orbital's, the probability of interaction increases



L_3-edge
L_2-edge
L_1-edge

K-edge

Cd and Cu absorption edges

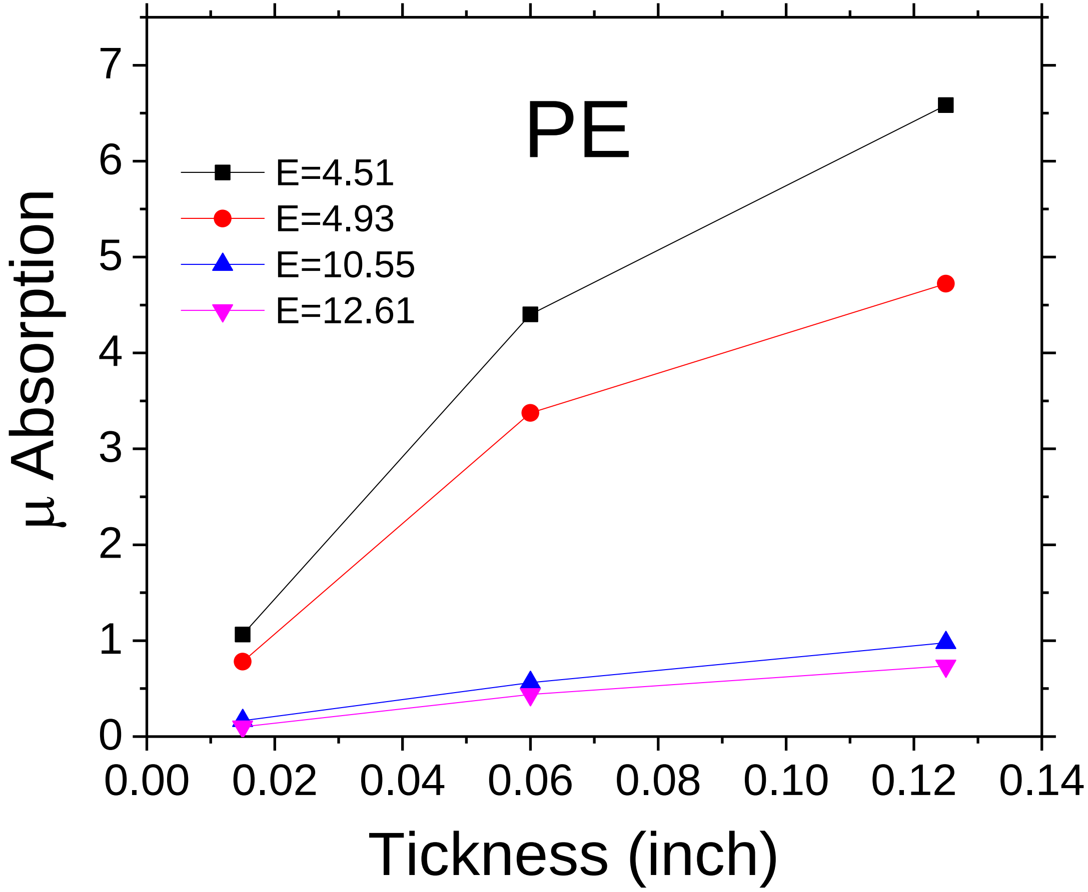


8980-933 = 8000 ev

Absorption as function of thickness

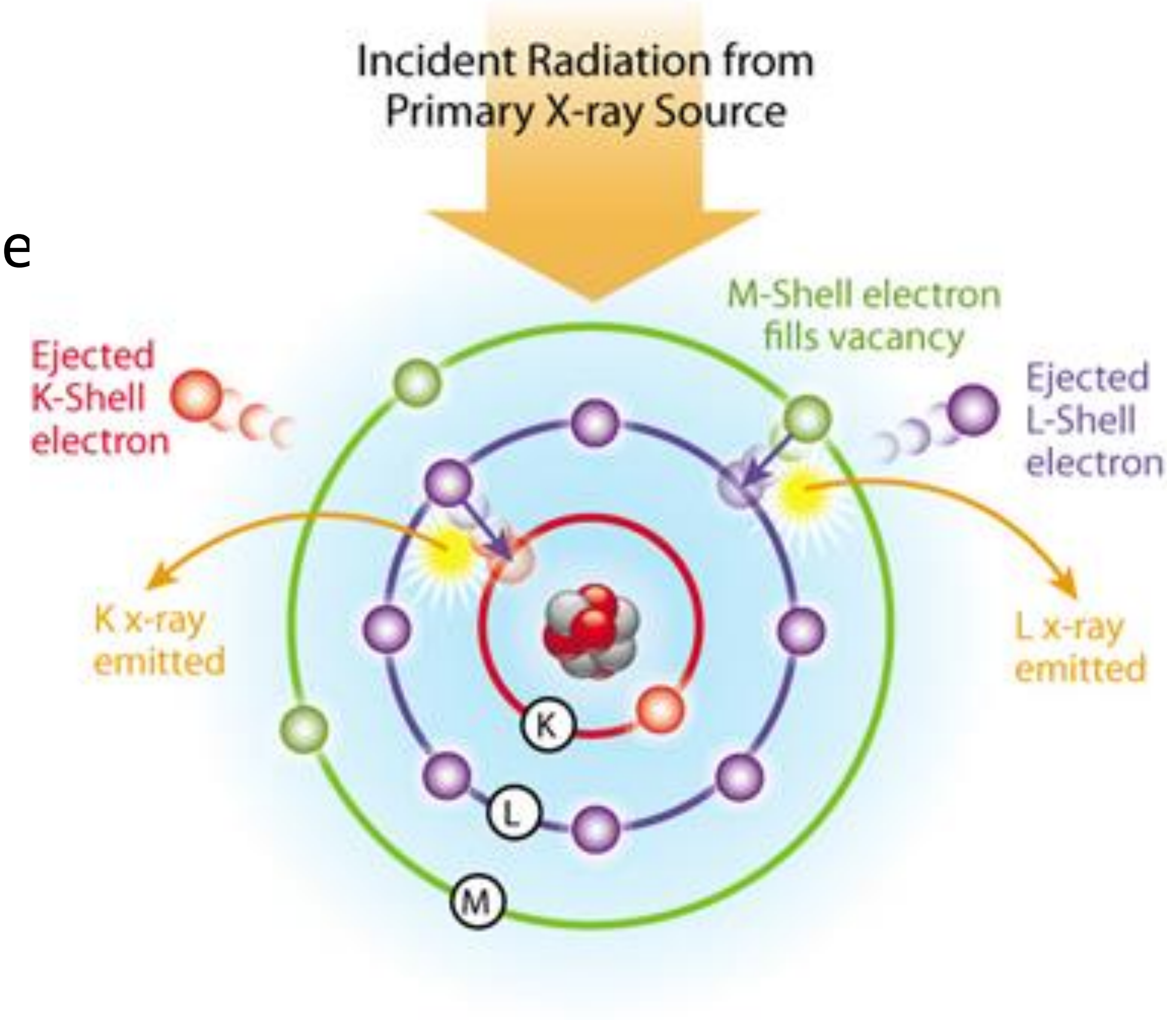
- ☐ X-ray attenuation for a polyethylene sample

Paramos aqui
28/10/2022



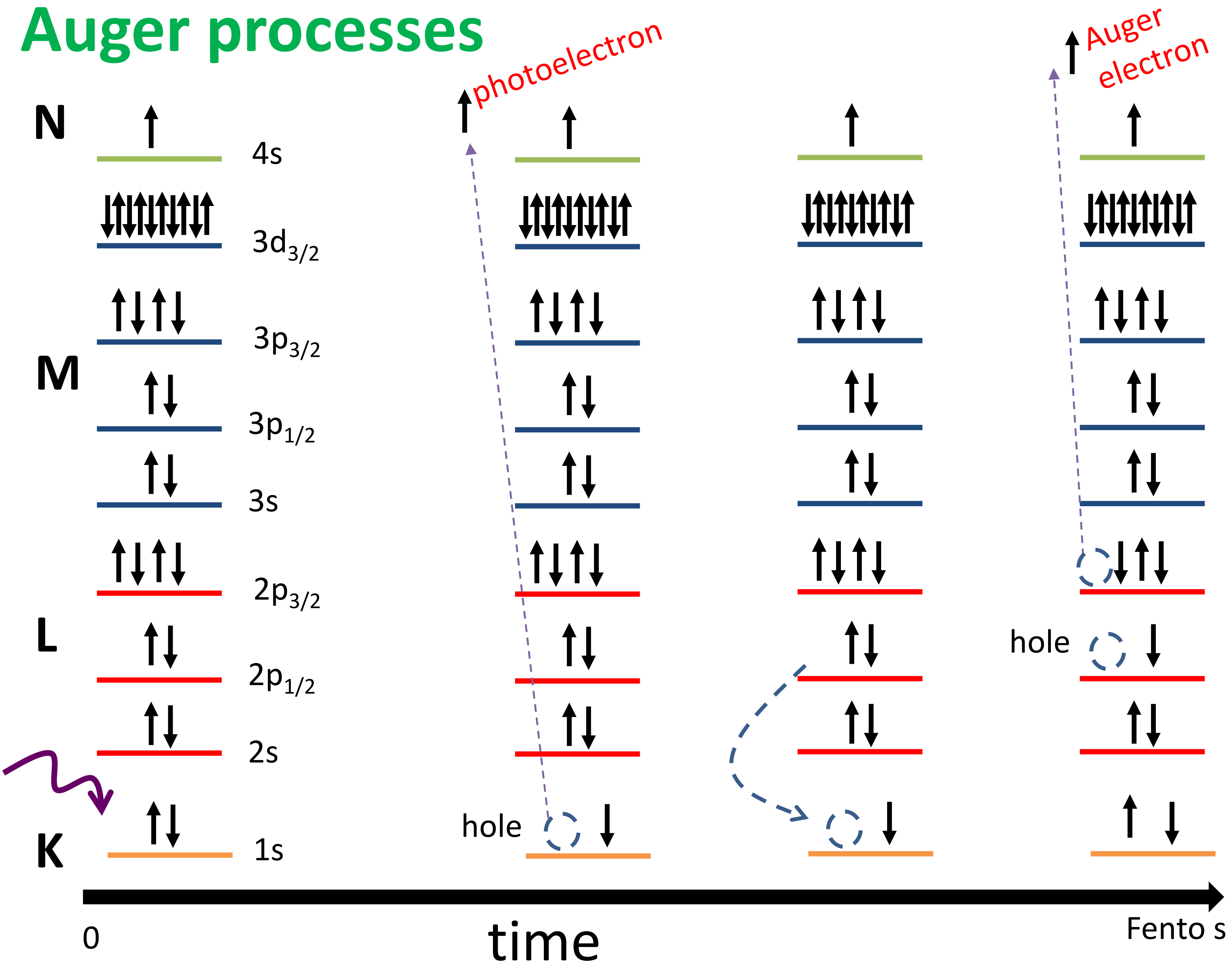
Relaxation processes

- ❑ Auger emission
- ❑ X-ray fluorescence

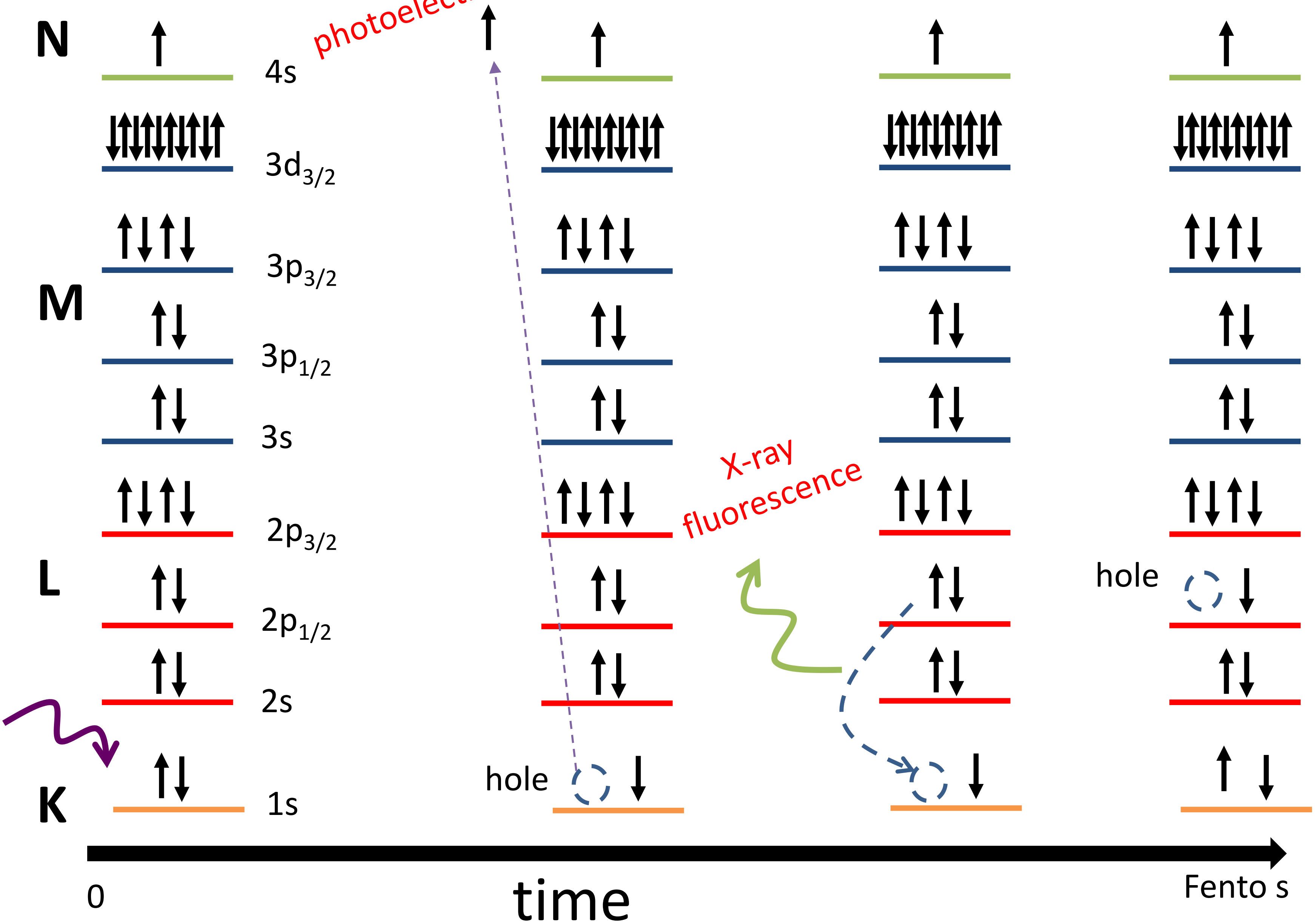


https://wiki.utep.edu/download/attachments/67371770/XRF%20fig%200.png?version=1&modificationDate=1384724989903&api=v2

Auger processes

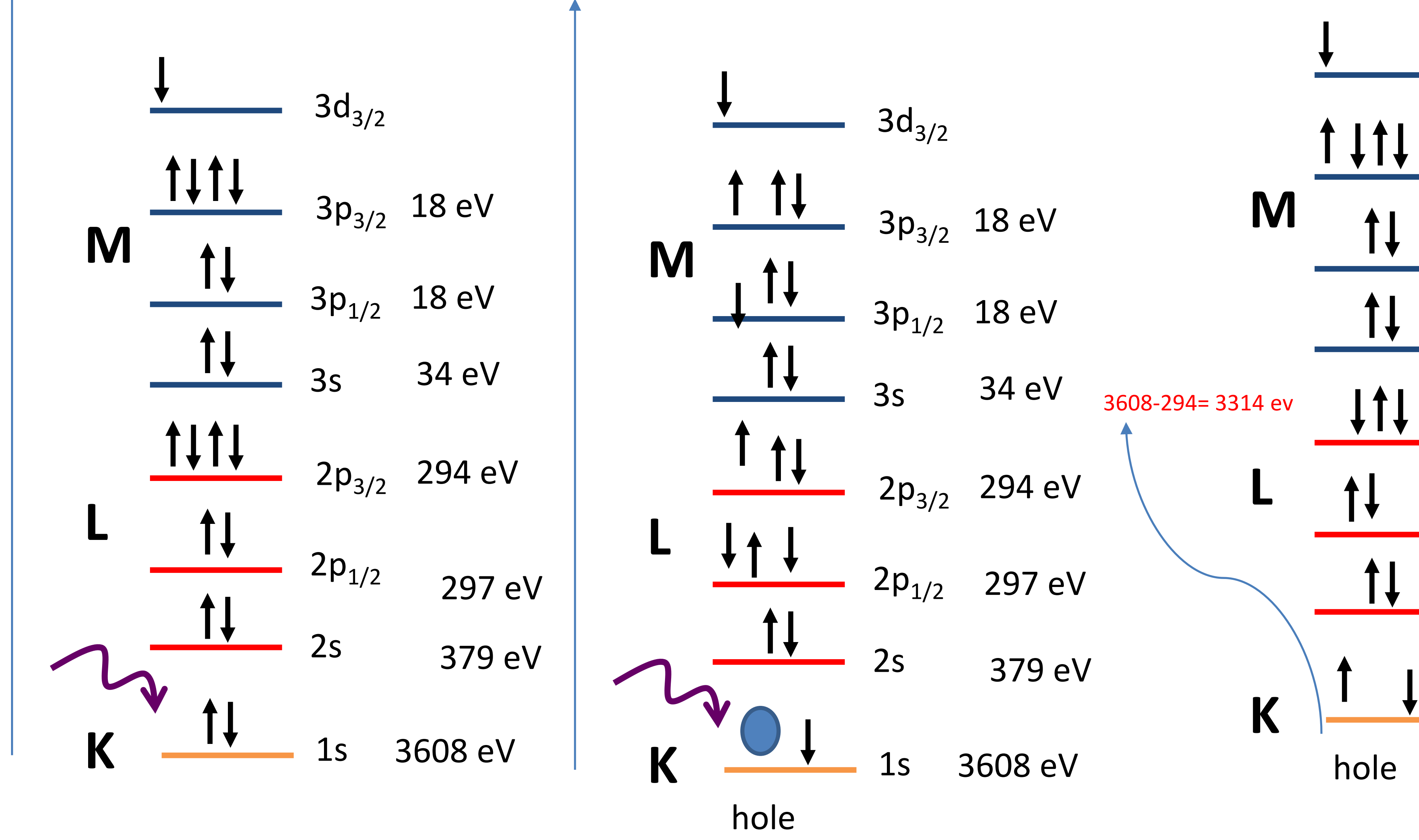


Fluorescence processes



Potassium atom

$KE = 1/2mv^2 = h\nu\ (eV) – E_{binding}\ (eV) – \phi$ (work function)

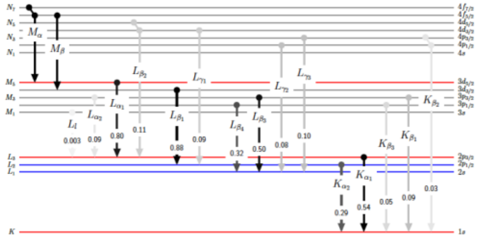


X-ray Absorption and Emission Energies of the Elements

Atomic Data and Energies from
W. T. Elam, B. D. Ravel and J. R. Sieber,
Radiation Physics and Chemistry **63**, pp 121-128 (2002)

Common oxidation states from wikipedia.org, after
N. N. Greenwood and A. Earnshaw,
Chemistry of the Elements, 2nd ed. (1997).

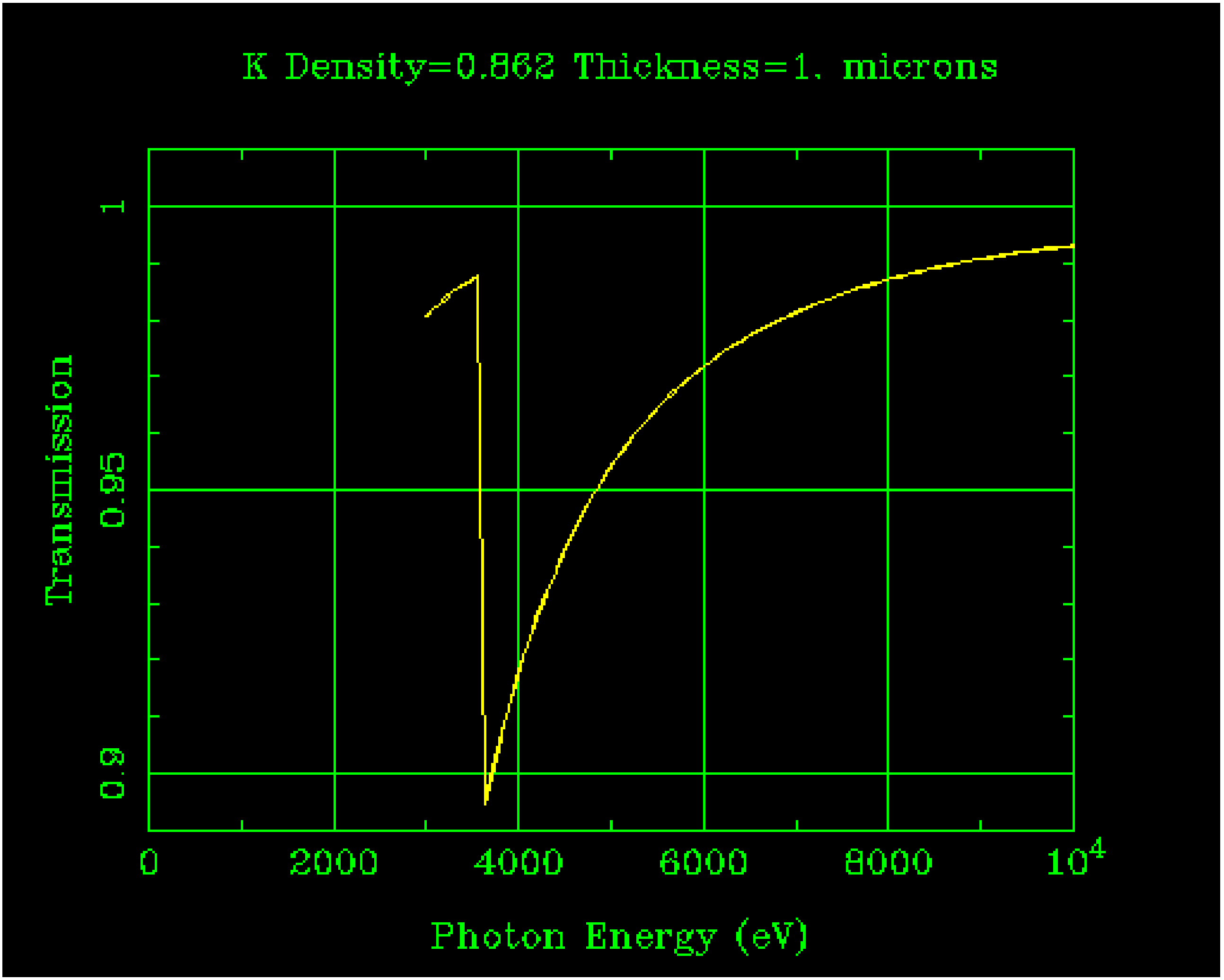
All energies in eV.
Emission line strengths are approximate, and vary with element.



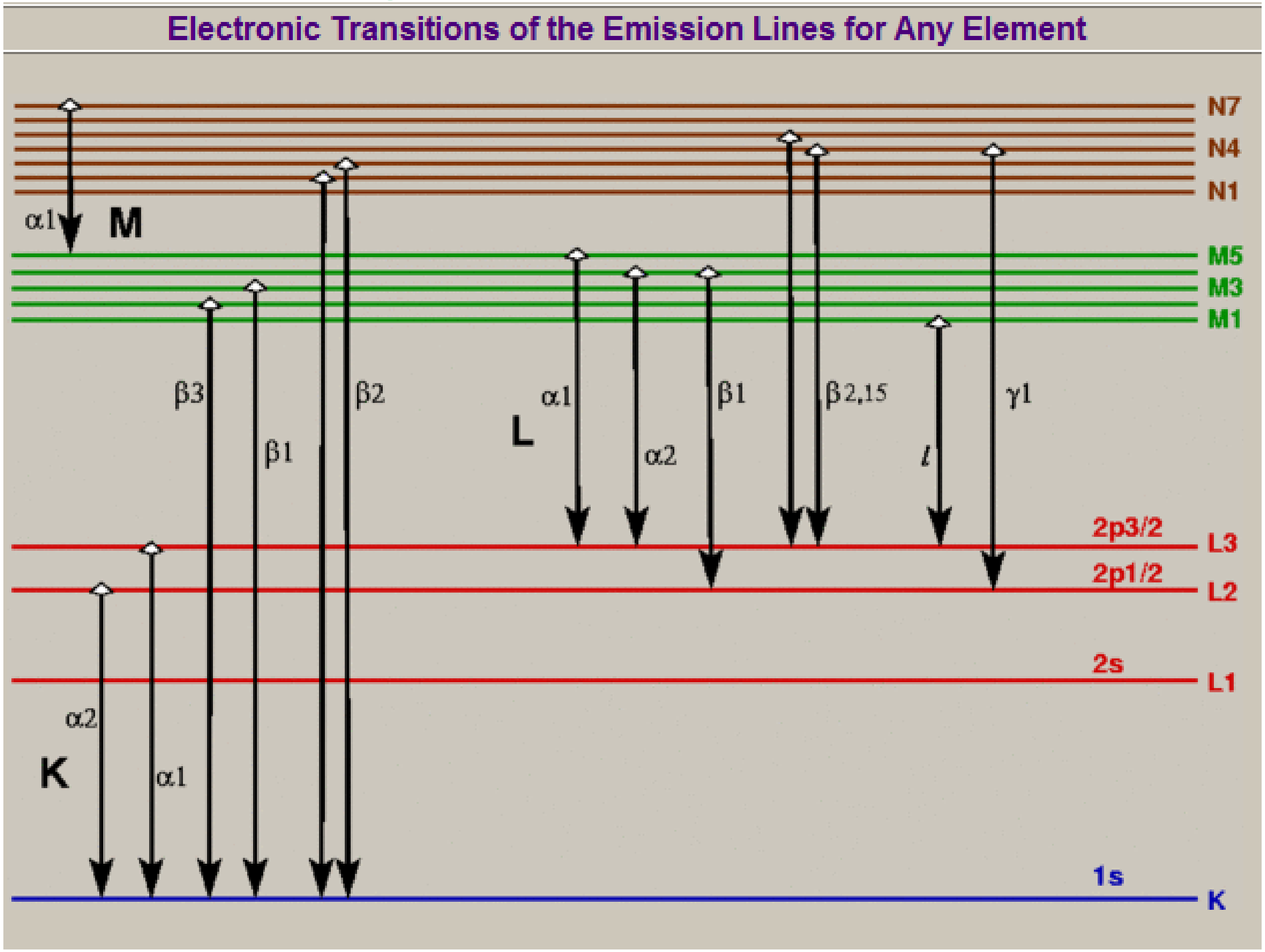
Symbol	Z	name	K edge	K_{α_1}	K_{β_1}	L_1 edge	L_{β_3}	L_{β_4}	L_2 edge	L_{β_1}	L_{γ_1}	L_3 edge	L_{α_1}	L_{β_2}	M_5 edge	M_α	M_β	Mass	oxidation states
H	1	hydrogen	14															1.0079	+1
He	2	helium	25															4.0026	
Li	3	lithium	55			5												6.941	+1
Be	4	beryllium	112	108		8			3			3						9.0122	+2
B	5	boron	188	183		13			5			5						10.81	+3
C	6	carbon	284	277		18			7			7						12.011	-4, -3, . . . , +2, +3, +4
N	7	nitrogen	410	392		37			18			18						14.0067	-3, +3, +5
O	8	oxygen	543	525		42			18			18						15.9994	-2
F	9	fluorine	697	677		45			20			20						18.9984	-1
Ne	10	neon	870	849		48			22			22						20.179	
Na	11	sodium	1071	1040		64			30			30						22.9898	+1
Mg	12	magnesium	1303	1254	1302	89	88	88	50			49						24.305	+2
Al	13	aluminum	1559	1486	1557	118	116	116	73			72						26.9815	+3
Si	14	silicon	1839	1740	1837	150	148	148	100			99						28.0855	-4, +4
P	15	phosphorus	2146	2010	2140	189	183	182	136			135						30.9738	-3, +3, +5
S	16	sulfur	2472	2310	2465	231	224	223	164			162						32.06	-2, +2, +4, +6
Cl	17	chlorine	2822	2622	2812	270	260	260	202			200						35.453	-1, +1, +3, +5, +7
Ar	18	argon	3206	2958	3190	326	311	310	251			248						39.948	
K	19	potassium	3608	3314	3590	379	360	360	297			295						39.0983	+1
Ca	20	calcium	4038	3692	4013	438	413	413	350			346						40.08	+2
Sc	21	scandium	4492	4093	4464	498	470	470	404			399						44.9559	+3
Ti	22	titanium	4966	4512	4933	561	528	528	460	458		454	452		2			47.88	+3, +4
V	23	vanadium	5465	4953	5428	627	590	590	520	518		512	510		2			50.9415	+2, +3, +4, +5
Cr	24	chromium	5989	5415	5947	696	654	654	584	582		574	572		2			51.996	+2, +3, +6
Mn	25	manganese	6539	5900	6492	769	722	722	650	648		639	637		2			54.938	+2, +3, +4, +7
Fe	26	iron	7112	6405	7059	845	792	792	720	718		707	705		2			55.847	+2, +3
Co	27	cobalt	7709	6931	7649	925	865	866	793	790		778	775		3			58.9332	+2, +3
Ni	28	nickel	8333	7480	8267	1009	942	941	870	866		853	849		4			58.69	+2
Cu	29	copper	8979	8046	8904	1097	1022	1019	952	947		933	928		5			63.546	+1, +2
Zn	30	zinc	9659	8637	9570	1196	1108	1105	1045	1035		1022	1012		10			65.38	+2
Ga	31	gallium	10367	9251	10267	1299	1199	1196	1143	1124		1116	1098		19			69.72	+3
Ge	32	germanium	11103	9886	10982	1415	1294	1290	1248	1218		1217	1188		29			72.59	-4, +2, +4
As	33	arsenic	11867	10543	11726	1527	1386	1381	1359	1317		1324	1282		42			74.9216	-3, +3, +5
Se	34	selenium	12658	11224	12497	1652	1491	1486	1474	1419		1434	1379		55			78.96	-2, +2, +4, +6
Br	35	bromine	13474	11924	13292	1782	1600	1593	1596	1526		1550	1481		69			79.904	-1, +1, +3, +5
Kr	36	krypton	14326	12648	14112	1921	1707	1699	1731	1636		1678	1585		94			83.8	
Rb	37	rubidium	15200	13396	14961	2065	1826	1816	1864	1751		1804	1692		112			85.4678	+1
Sr	38	strontium	16105	14165	15835	2216	1946	1936	2007	1871		1940	1806		134			87.62	+2
Y	39	yttrium	17038	14958	16739	2373	2074	2062	2156	1998		2080	1924		156			88.9059	+3
Zr	40	zirconium	17998	15775	17668	2532	2202	2188	2307	2126		2223	2044		179			91.22	+4
Nb	41	niobium	18986	16615	18625	2698	2337	2322	2465	2260		2371	2169		202			92.9064	+4, +5
Mo	42	molybdenum	20000	17480	19606	2866	2472	2454	2625	2394		2520	2292		228			95.94	+3, +4, +6
Tc	43	technetium	21044	18367	20626	3043	2625	2595	2793	2535		2677	2423		254			97.907	+4, +7
Ru	44	ruthenium	22117	19279	21656	3224	2762	2741	2967	2683		2838	2558		280			101.07	+3, +4, +6
Rh	45	rhodium	23220	20216	22724	3412	2916	2891	3146	2834	3144	3004	2697	3002	307			102.906	+2, +3, +4
Pd	46	palladium	24350	21177	23818	3604	3072	3044	3330	2990	3328	3173	2838	3171	335			106.42	+2, +4
Ag	47	silver	25514	22163	24941	3806	3233	3202	3524	3150	3520	3351	2983	3347	368			107.868	+1
Cd	48	cadmium	26711	23173	26093	4018	3400	3365	3727	3315	3715	3538	3133	3526	405			112.41	+2
In	49	indium	27940	24210	27275	4238	3573	3535	3938	3487	3920	3730	3286	3712	444			114.82	+3
Sn	50	tin	29200	25271	28485	4465	3750	3708	4156	3663	4131	3929	3444	3904	485			118.69	-4, +2, +4
Sb	51	antimony	30491	26359	29725	4698	3932	3885	4380	3842	4347	4132	3604	4099	528	528	538	121.75	-3, +3, +5
Te	52	tellurium	31814	27473	30993	4939	4118	4068	4612	4029	4570	4341	3768	4299	573	573	583	127.6	-2, +2, +4, +6
I	53	iodine	33169	28612	32294	5188	4313	4257	4852	4221	4801	4557	3938	4506	619	619	631	126.905	-1, +1, +3, +5, +7
Xe	54	xenon	34561	29775	33620	5453	4512	4451	5107	4418	5038	4786	4110	4716	676	676	689	131.29	
Cs	55	cesium	35985	30973	34982	5714	4711	4643	5359	4618	5279	5012	4285	4932	727	727	740	132.905	+1
Ba	56	barium	37441	32194	36378	5989	4926	4852	5624	4828	5531	5247	4466	5154	780	780	796	137.33	+2
La	57	lanthanum	38925	33442	37797	6266	5138	5057	5891	5038	5786	5483	4647	5378	836	836	853	138.906	+3
Ce	58	cerium	40443	34720	39256	6548	5361	5274	6164	5262	6055	5723	4839	5614	884	884	902	140.12	+3, +4
Pr	59	praseodymium	41991	36027	40749	6835	5593	5498	6440	5492	6325	5964	5035	5849	929	927	946	140.908	+3, +4
Nd	60	neodymium	43569	37361	42272	7126	5829	5723	6722	5719	6602	6208	5228	6088	980	979	1002	144.24	+3
Pm	61	promethium	45184	38725	43827	7428	6071	5957	7013	5961	6893	6459	5432	6339	1027	1023	1048	144.913	+3
Sm	62	samarium	46834	40118	45414	7737	6317	6196	7312	6201	7183	6716	5633	6587	1083	1078	1106	150.36	+3
Eu	63	europium	48519	41542	47038	8052	6571	6438	7617	6458	7484	6977	5850	6844	1128	1122	1153	151.96	+2, +3
Gd	64	gadolinium	50239	42996	48695	8376	6832	6688	7930	6708	7787	7243	6053	7100	1190	1181	1213	157.25	+3
Tb	65	terbium	51996	44482	50385	8708	7097	6940	8252	6975	8102	7514	6273	7364	1241	1233	1269	158.925	+3, +4
Dy	66	dysprosium	53789	45999	52113	9046	7370	7204	8581	7248	8427	7790	6498	7636	1292	1284	1325	162.5	+3
Ho	67	holmium	55618	47547	53877	9394	7653	7471	8918	7526	8758	8071	6720	7911	1351	1342	1383	164.93	+3
Er	68	erbium	57486	49128	55674	9751	7939	7745	9264	7811	9096	8358	6949	8190	1409	1404	1448	167.26	+3
Tm	69	thulium	59390	50742	57505	10116	8231	8026	9617	8102	9442	8648	7180	8472	1468	1463	1510	168.934	+3
Yb	70	ytterbium	61332	52388	59382	10486	8536	8313	9978	8402	9787	8944	7416	8753	1528	1526	1574	173.04	+3
Lu	71	lutetium	63314	54070	61290	10870	8846	8606	10349	8710	10143	9244	7655	9038	1589	1580	1630	174.967	+3
Hf	72	hafnium	65351	55790	63244	11271	9164	8906	10739	9023	10519	9561	7899	9341	1662	1646	1700	178.49	+4
Ta	73	tantalum	67416	57535	65222	11682	9488	9213	11136	9343	10898	9881	8146	9643	1735	1712	1770	180.948	+5
W	74	tungsten	69525	59318	67244	12100	9819	9525	11544	9672	11288	10207	8398	9951	1809	1775	1838	183.85	+4, +6
Re	75	rhenium	71676	61141	69309	12527	10160	9845	11959	10010	11685	10535	8652	10261	1883	1840	1906	186.207	+4
Os	76	osmium	73871	63000	71414	12968	10511	10176	12385	10354	12092	10871	8911	10578	1960	1907	1978	190.2	+4
Ir	77	iridium	76111	64896	73560	13419	10868	10510	12824	10708	12512	11215	9175	10903	2040	1976	2052	192.22	+3, +4
Pt	78	platinum	78395	66831	75750	13880	11235	10853	13273	11071	12941	11564	9442	11232	2122	2048	2128	195.08	+2, +4
Au	79	gold	80725	68806	77982	14353	11610	11205	13734	11443	13381	11919	9713	11566	2206	2118	2203	196.967	+1, +3
Hg	80	mercury	83102	70818	80255	14839	11992	11560	14209	11824	13831	12284	9989	11906	2295	2191	2281	200.59	+1, +2
Tl	81	thallium	85530	72872	82573	15347	12390	11931	14698	12213	14292	12658	10269	12252	2389	2267	2363	204.383	+1, +3
Pb	82	lead	88005	74970	84939	15861	12795	12307	15200	12614	14766	13035	10551	12601	2484	2342	2444	207.2	+2, +4
Bi	83	bismuth	90526	77107	87349	16388	13211	12692	15711	13023	15247	13419	10839	12955	2580	2418	2526	208.98	+3, +5
Po	84	polonium	93105	79291	89803	16939	13637	13085	16244	13446	15744	13814	11131	13314	2683	2499	2614	208.982	-2, +2, +4
At	85	astatine	95730	81516	92304	17493	14067	13485	16785	13876	16252	14214	11427	13681	2787	2577	2699	209.987	-1, +1
Rn	86	radon	98404	83785	94866	18049	14511	13890	17337	14315	16770	14619	11727	14052	2892	2654	2784	222.018	
Fr	87	francium	101137	86106	97474	18639	14976	14312	17907	14771	17304	15031	12031	14428	3000	2732	2868	223.02	+1
Ra	88	radium	103922	88478	100130	19237	15445	14747	18484	15236	17848	15444	12339	14808	3105	2806	2949	226.025	+2
Ac	89	actinium	106755	90884	102846	19840	15931	15184	19083	15713	18408	15871	12652	15196	3219	2900	3051	227.028	+3
Th	90	thorium	109651	93351	105605	20472	16426	15642	19693	16202	18981	16300	12968	15588	3332	2990	3149	232.038	+4
Pa	91	protactinium	112601	95868	108427	21105	16931	16104	20314	16703	19571	16733	13291	15990	3442	3071	3240	231.036	+5
U	92	uranium	115606	98440	111303	21757	17454	16575	20948	17220	20170	17166	13614	16388	3552	3164	3340	238.051	+4, +6
Np	93	neptunium	118669	101059	114234	22427	17992	17061	21600	17751	20784	17610	13946	16794	3664	3250	3435	237.048	+3, +4, +5
Pu	94	plutonium	121791	103734	117228	23104	18541	17557	22266	18296	21420	18057	14282	17211	3775	3339	3534	239.052	+3, +4, +5
Am	95	americium	124982	106472	120284	23808	19110	18069	22952	18856	22072	18510	14620	17630	3890	3429	3635	243.061	+3, +4, +5
Cm	96	curium	128241	109271	123403	24526	19688	18589	23651	19427	22735	18970	14961	18054	4009	3525	3740	247.07	+3
Bk	97	berkelium	131556	112121	126580	25256	20280	19118	24371	20018	23416	19435	15308	18480	4127	3616	3842	247.07	+3, +4
Cf	98	californium	134939	115032	129823	26010	20894	19665	25108	20624	24117	19907	15660	18916	4247	3709	3946	251.08	+3
Es	99	einsteinium																	
Fm	100	fermium																	
Md	101	mendelevium																	
No	102	nobelium																	
Lr	103	lawrencium																	


Marie Sklodowska Curie

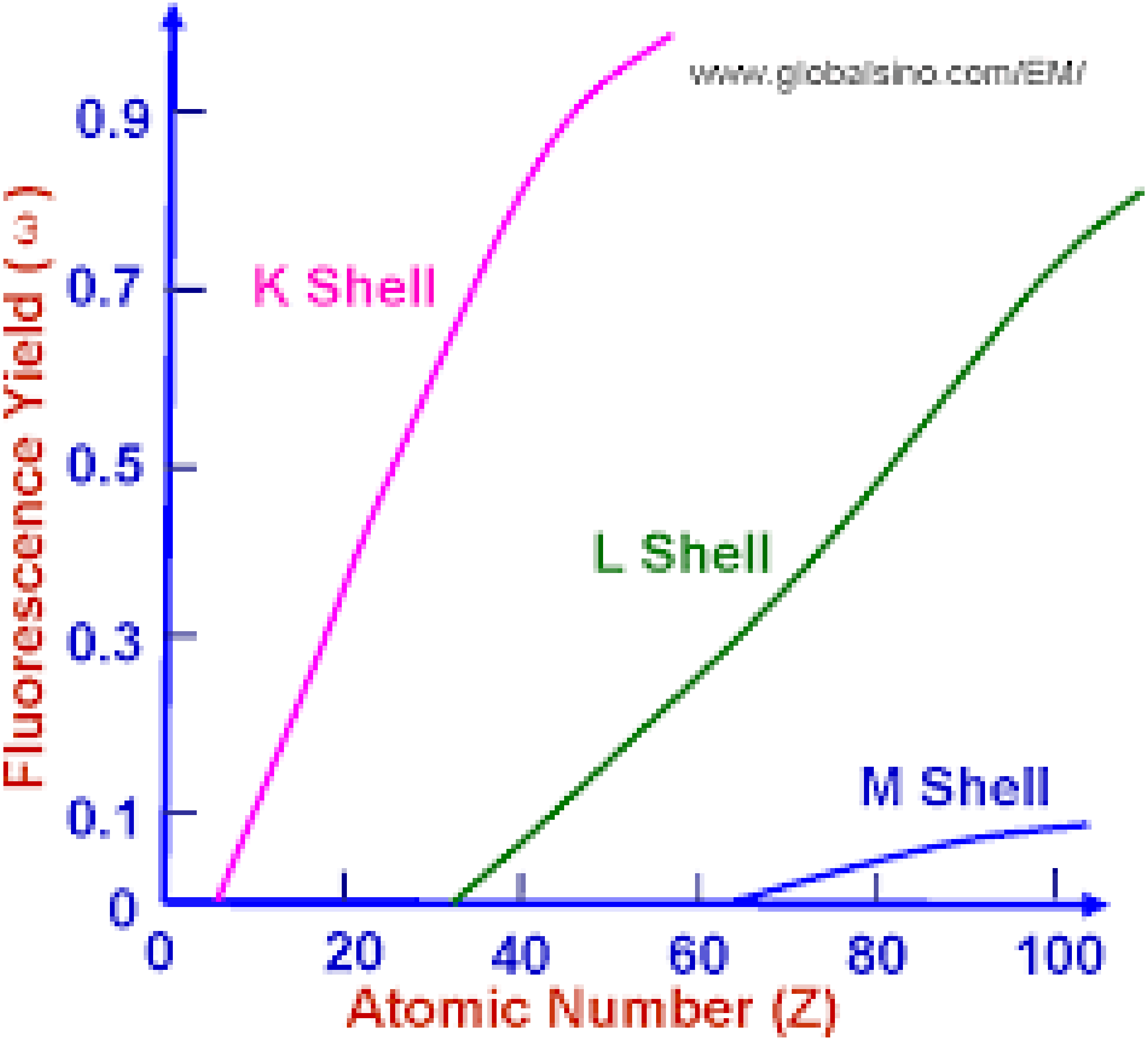
https://xrayabsorption.org/xraytable
Version 4, 2020-April-19


K Density=0.862 Thickness=1. microns
Transmission
1
0.95
0.9
0
2000
4000
6000
8000
10^4
Photon Energy (eV)

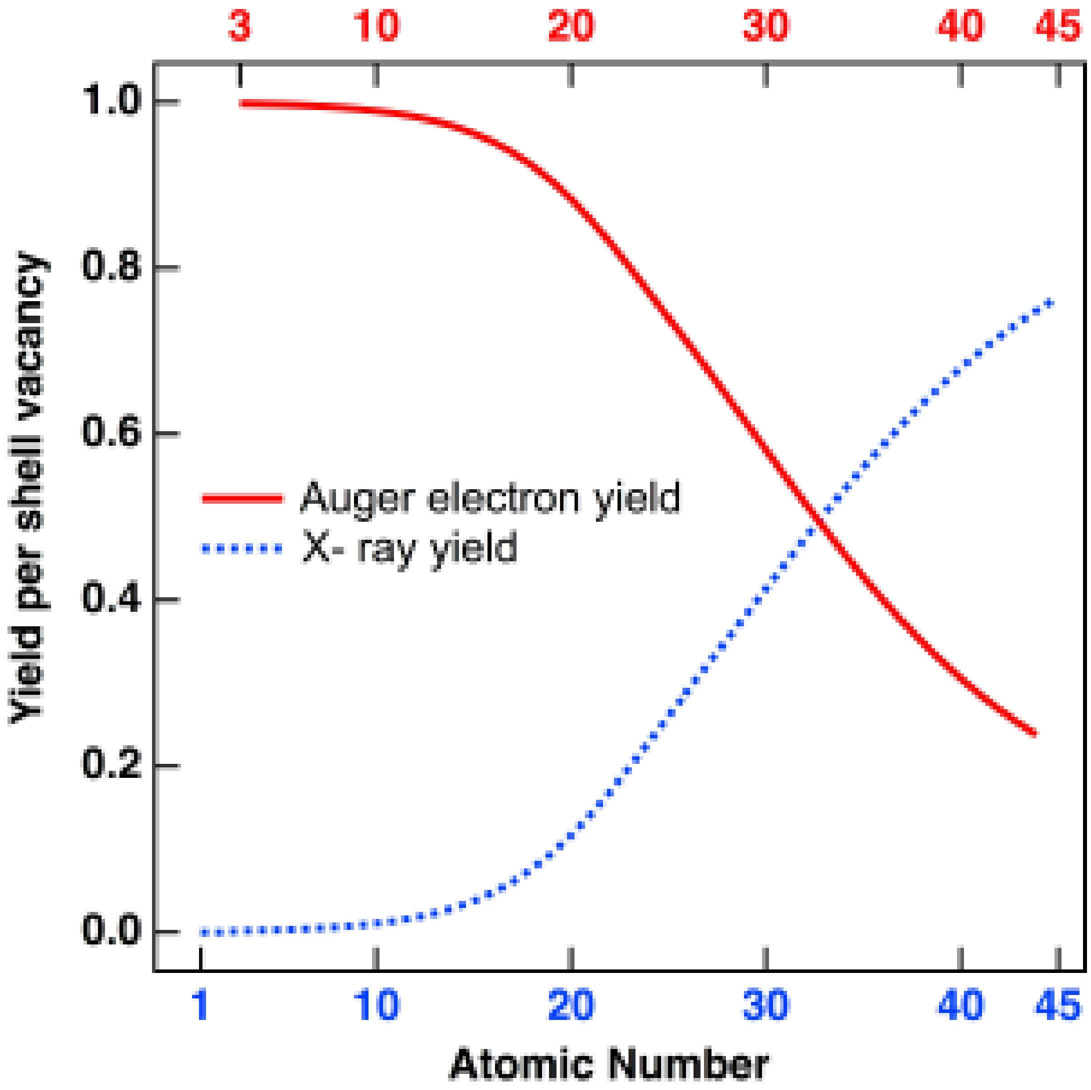
XRF Relaxation processes



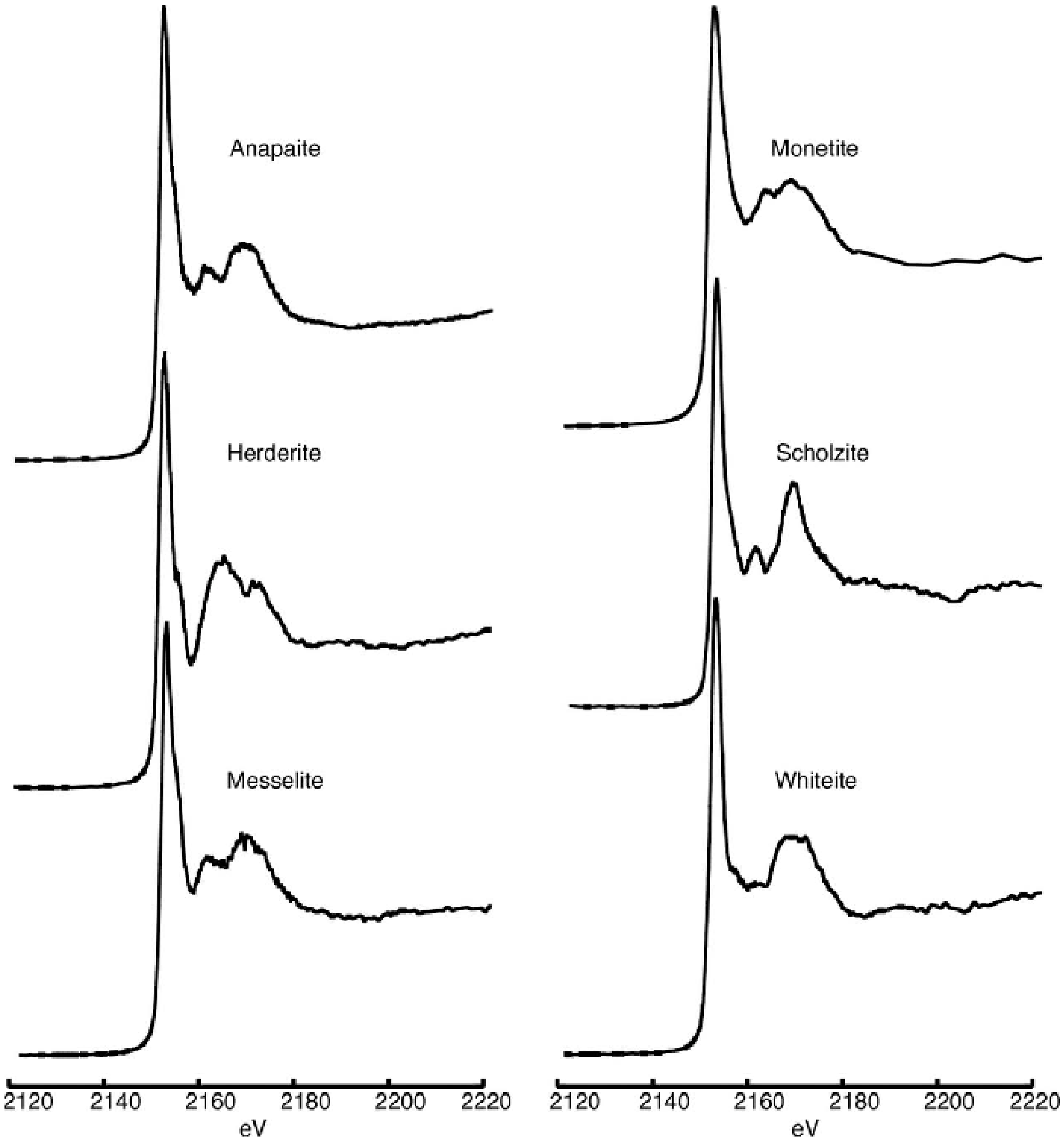
Hephasestus, By B. Ravel

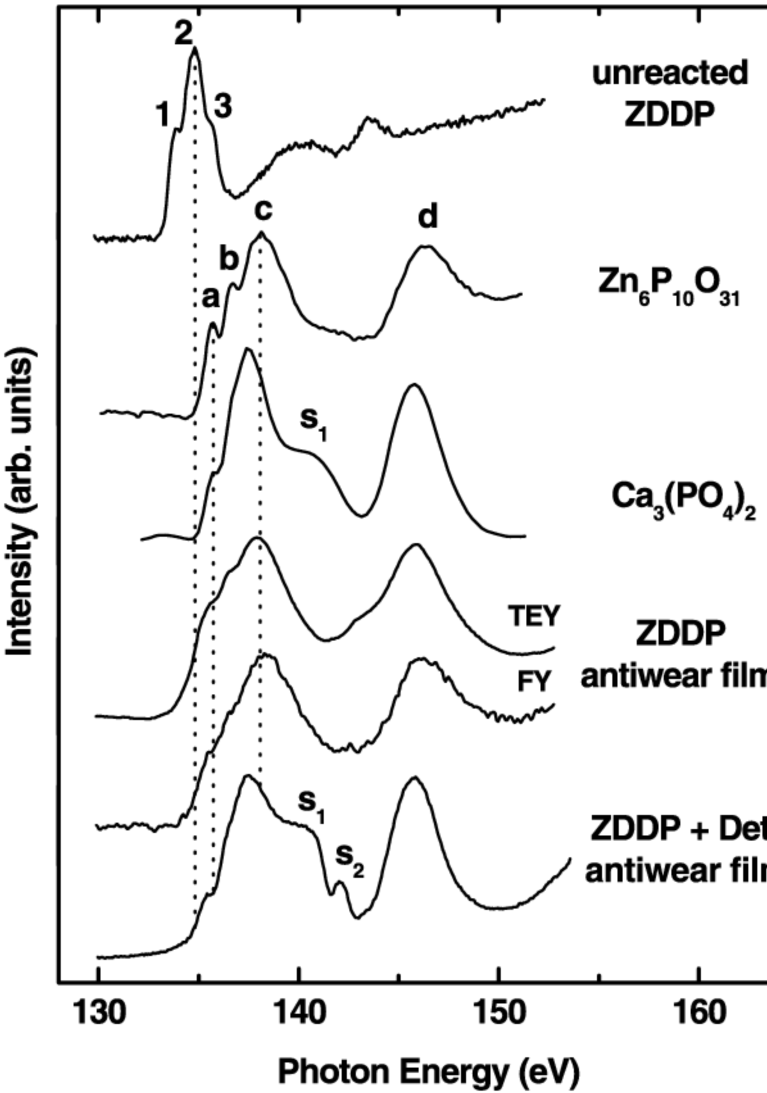

www.globalsino.com/EM/
Fluorescence Yield (ω)
0.9
0.7
0.5
0.3
0.1
0
K Shell
L Shell
M Shell
0
20
40
60
80
100
Atomic Number (Z)

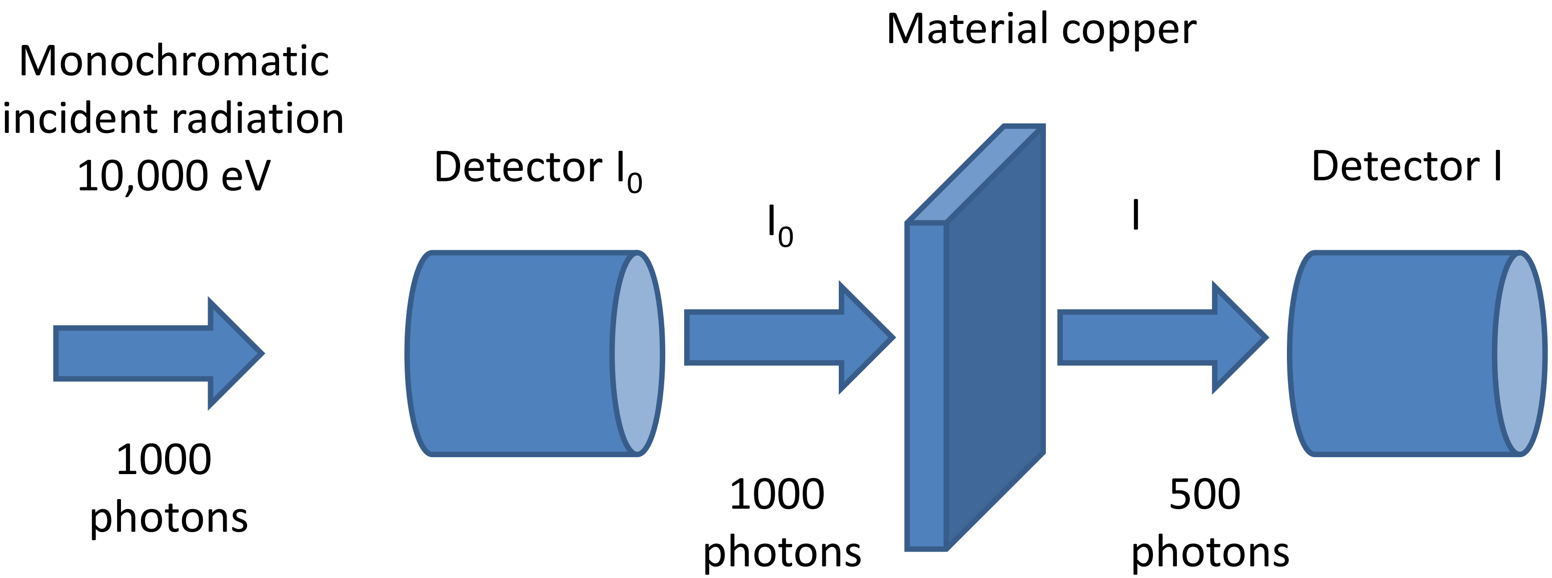
XRF versus Auger competition



https://upload.wikimedia.org/wikipedia/commons/thumb/5/54/Auger_xray_wiki_in_png_format.png/340px-Auger_xray_wiki_in_png_format.png


Anapaite
Herderite
Messelite
Monetite
Scholzite
Whiteite
2120
2140
2160
2180
2200
2220
eV


1
2
3
unreacted ZDDP
a
b
c
d
$Zn_6P_{10}O_{31}$
s_1
$Ca_3(PO_4)_2$
TEY
FY
ZDDP antiwear fil
s_1
s_2
ZDDP + Det
antiwear fil
Intensity (arb. units)
130
140
150
160
Photon Energy (eV)



Monochromatic
incident radiation
10,000 eV

1000
photons

Detector I_0

I_0

1000
photons

Material copper

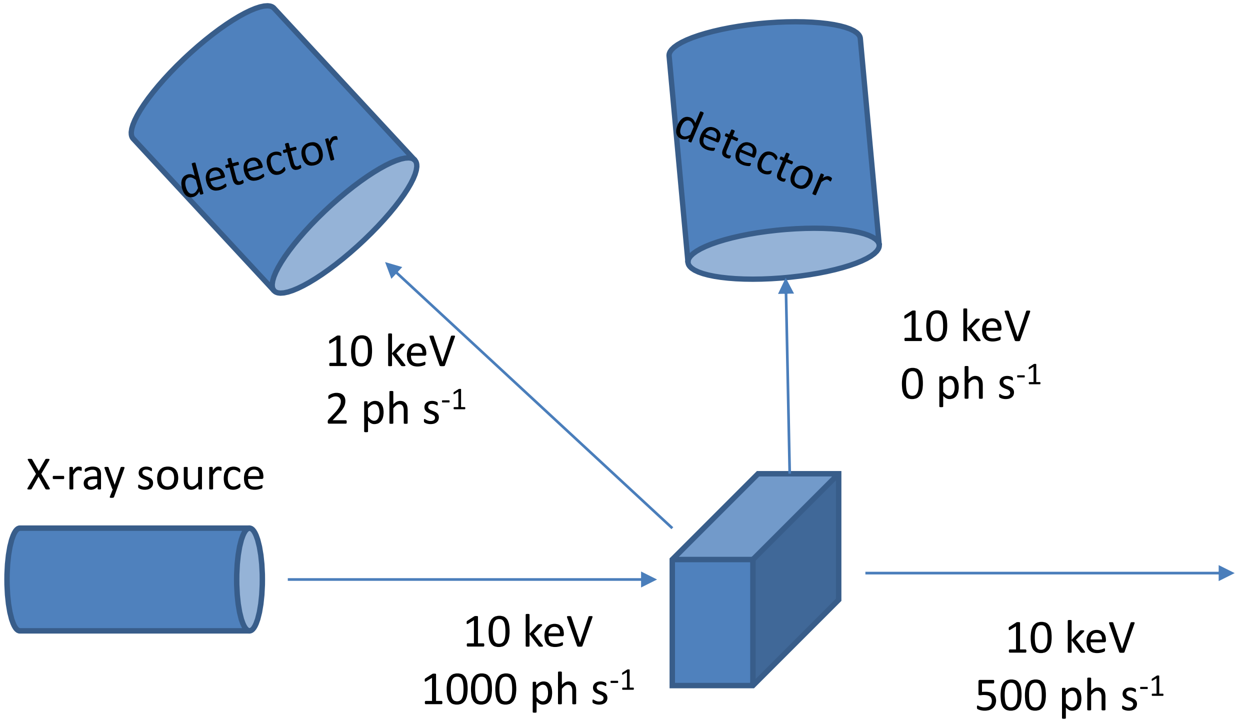
I

500
photons

Detector I

Transmittance= I/I_0

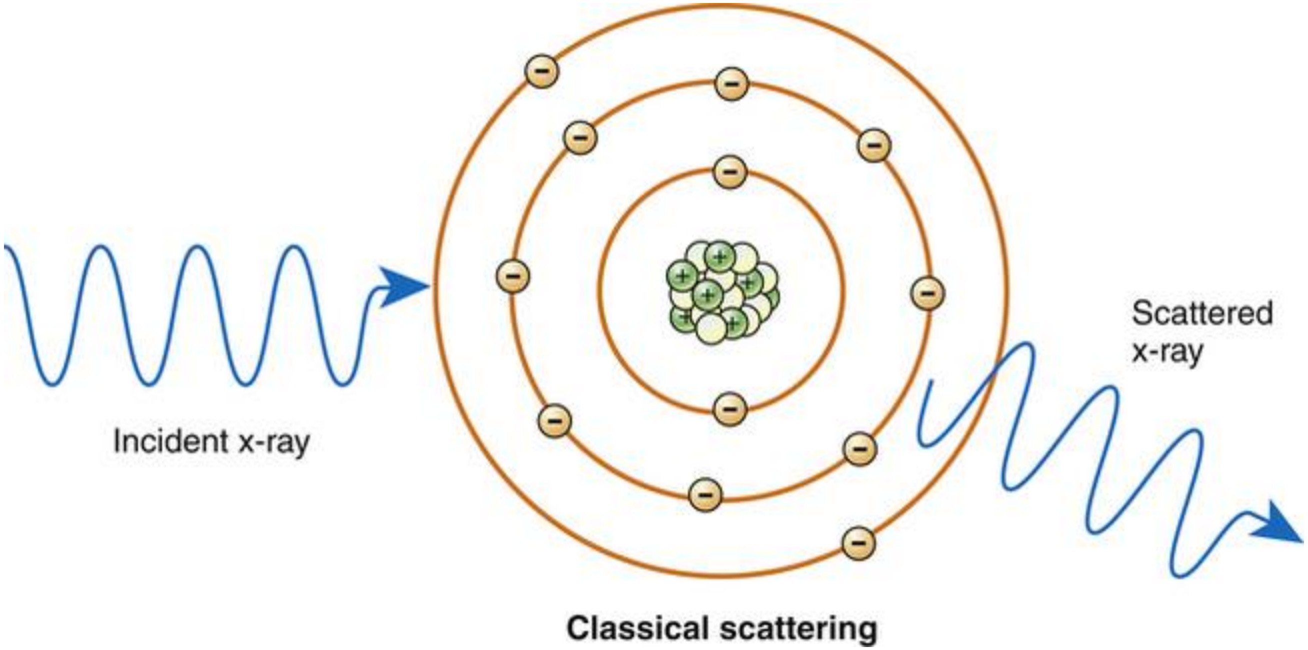
T = 0.5 or 50 %


detector
detector
10 keV
2 ph s^{-1}
10 keV
0 ph s^{-1}
X-ray source
10 keV
1000 ph s^{-1}
10 keV
500 ph s^{-1}

5.4 X-ray Thomson scattering

Thomson Scattering

- ☐ In Thomson scattering the energy of the photon does not change



http://radiologykey.com/wp-content/uploads/2016/02/B9780323069748100074_f07-02-9780323069748.jpg

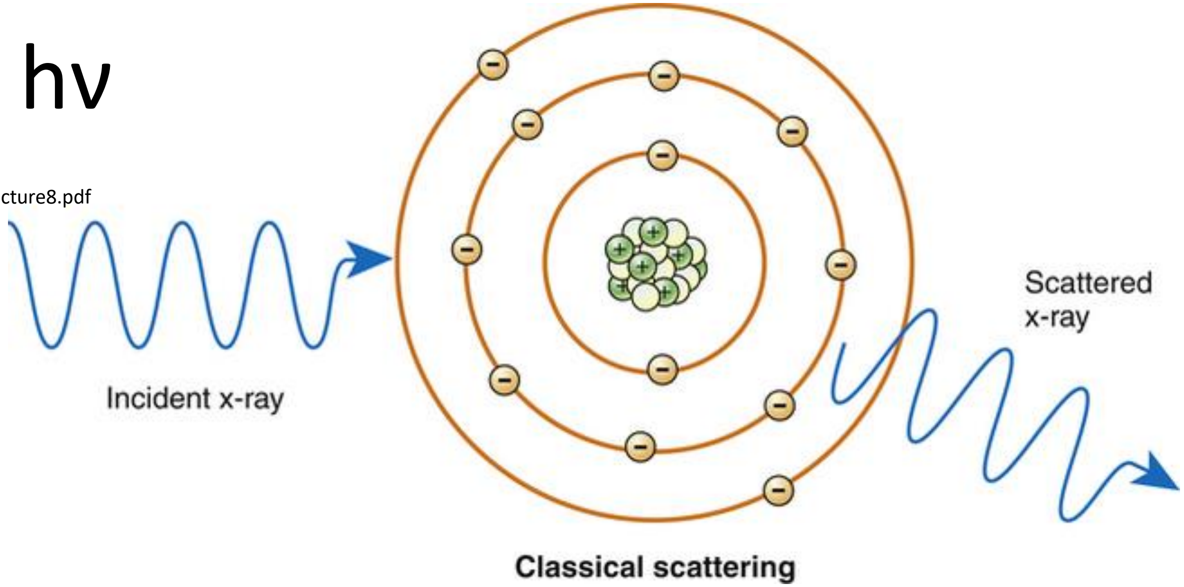
Dependence of E and Z

☐ For the energy range we are mostly interested, 1-100 keV, it is nearly constant up to 10 keV and then starts to decrease

☐ Since Thomson scattering is the result of the interaction between the photon and the electron it will increase is function of Z

$$\sigma_{Thomson} \propto Z / h\nu$$

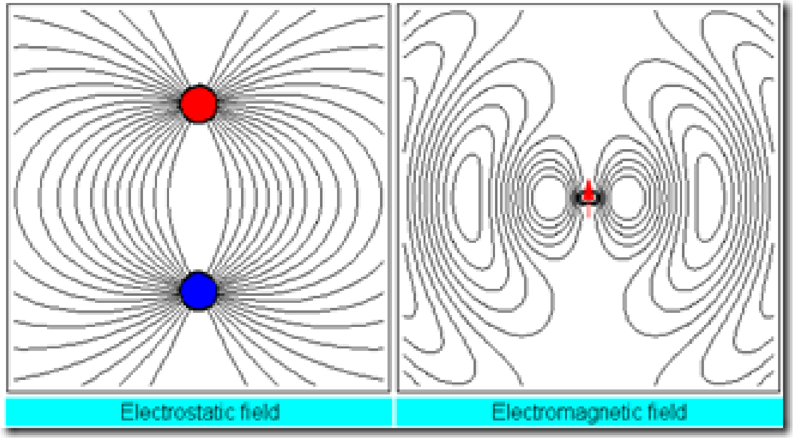
https://www.medphysics.wisc.edu/courses/mp501/501_lecture8.pdf



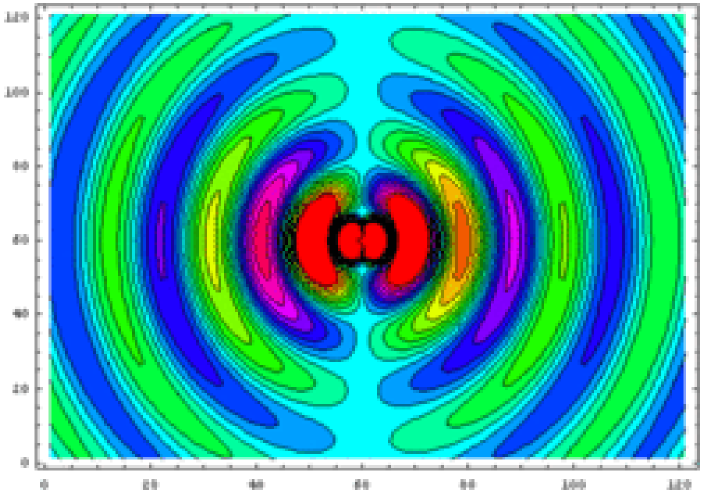
http://radiologykey.com/wp-content/uploads/2016/02/B9780323069748100074_f07-02-9780323069748.jpg

How does it take place?

- Dipole radiation



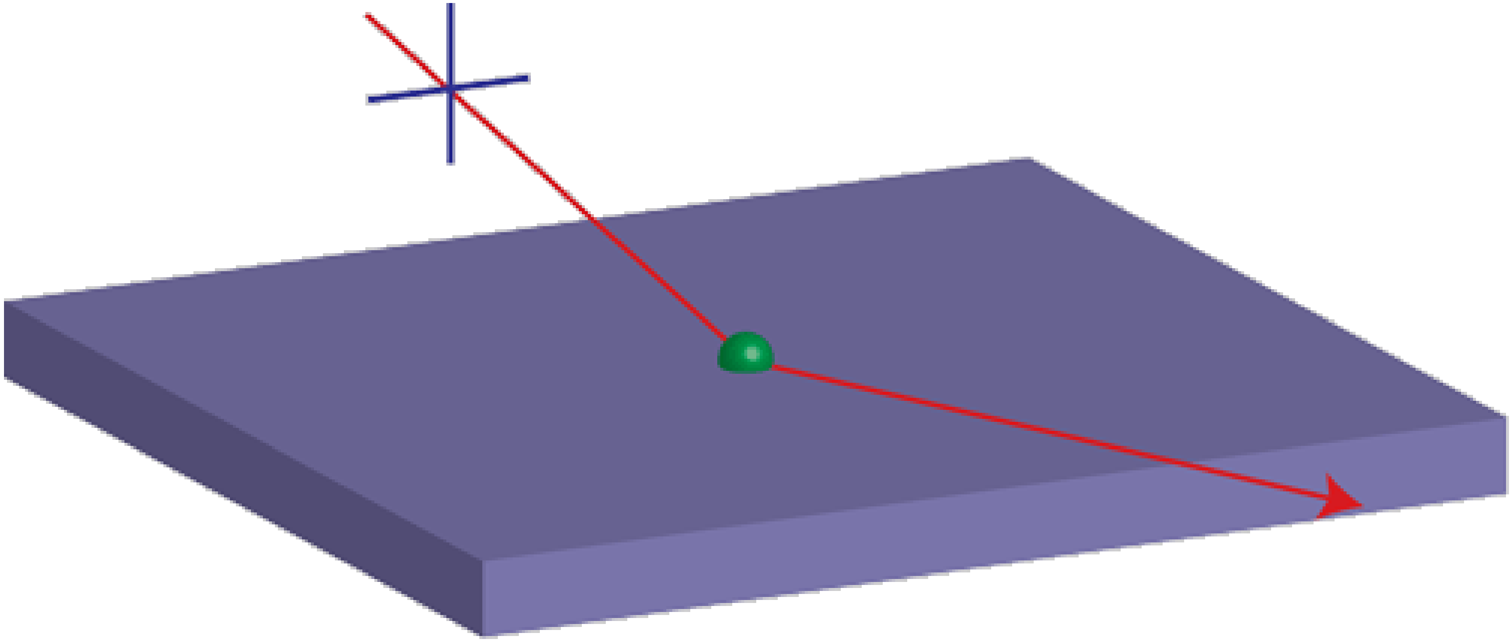
- In which direction is the electron moving?



http://allenluadvance.blogspot.com.br/2009/02/dipole-and-monopole-antenna-modeling.html

Thomson Scattering by metal surfaces

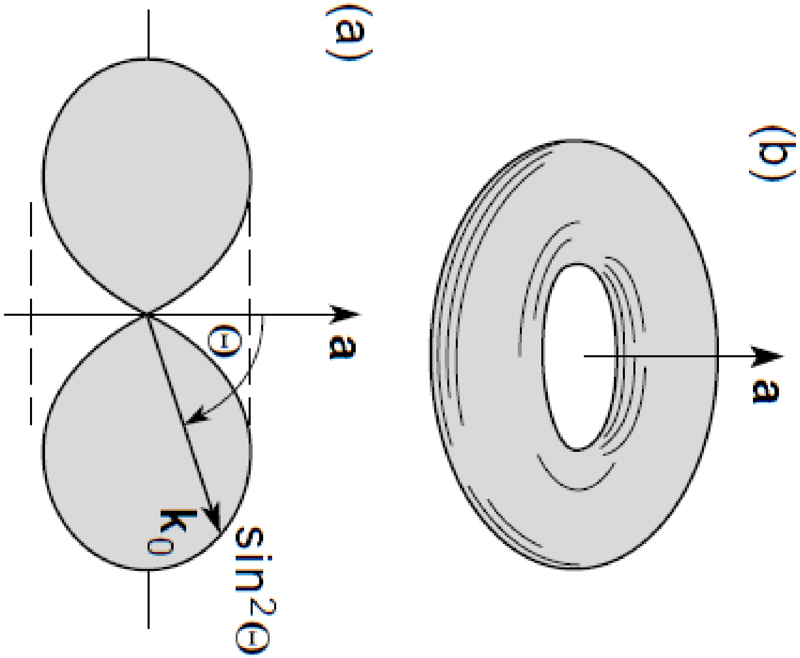
☐ Polarization by reflection

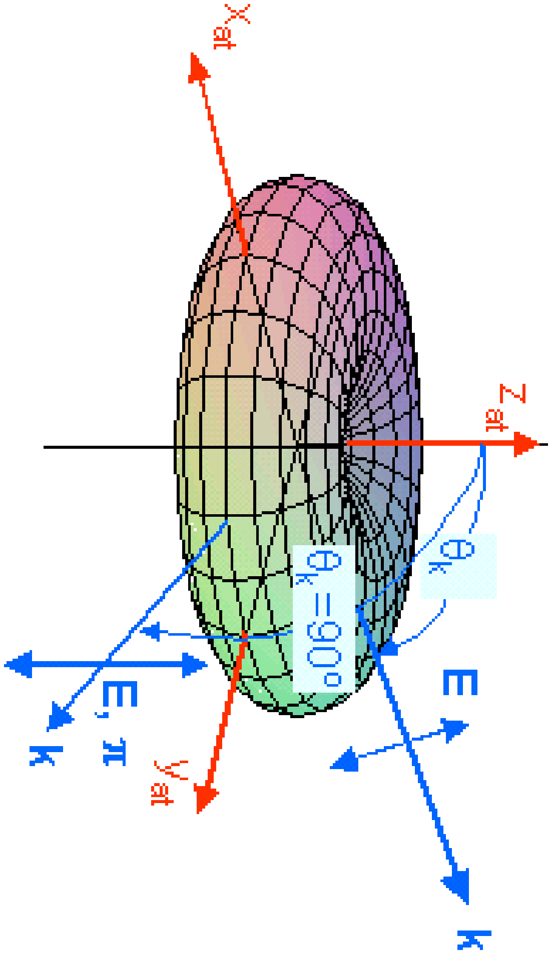


http://background.uchicago.edu/~whu/intermediate/Polarization/polscat.gif

Thomson Scattering of polarized radiation

- Dipole

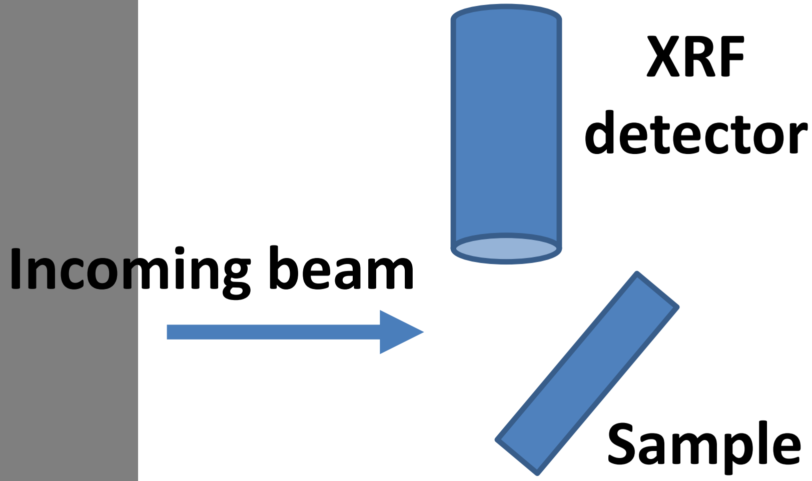


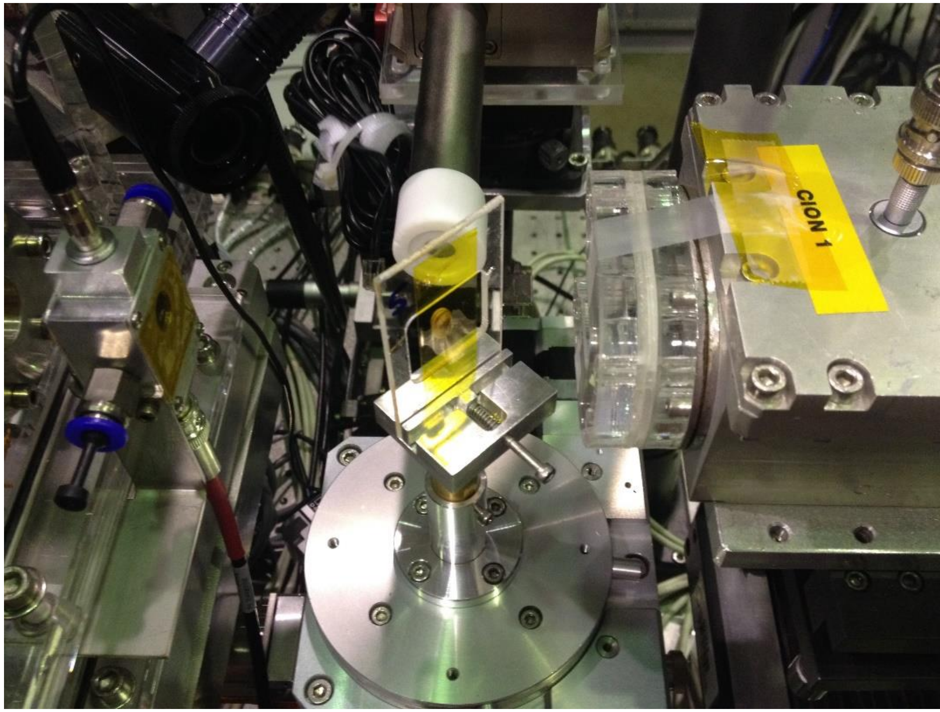


http://staff.mbi-berlin.de/hertel/physik3/chapter8/8.7html/01.htm

Thomson Scattering of polarized radiation

- XRF beamline@LNLS

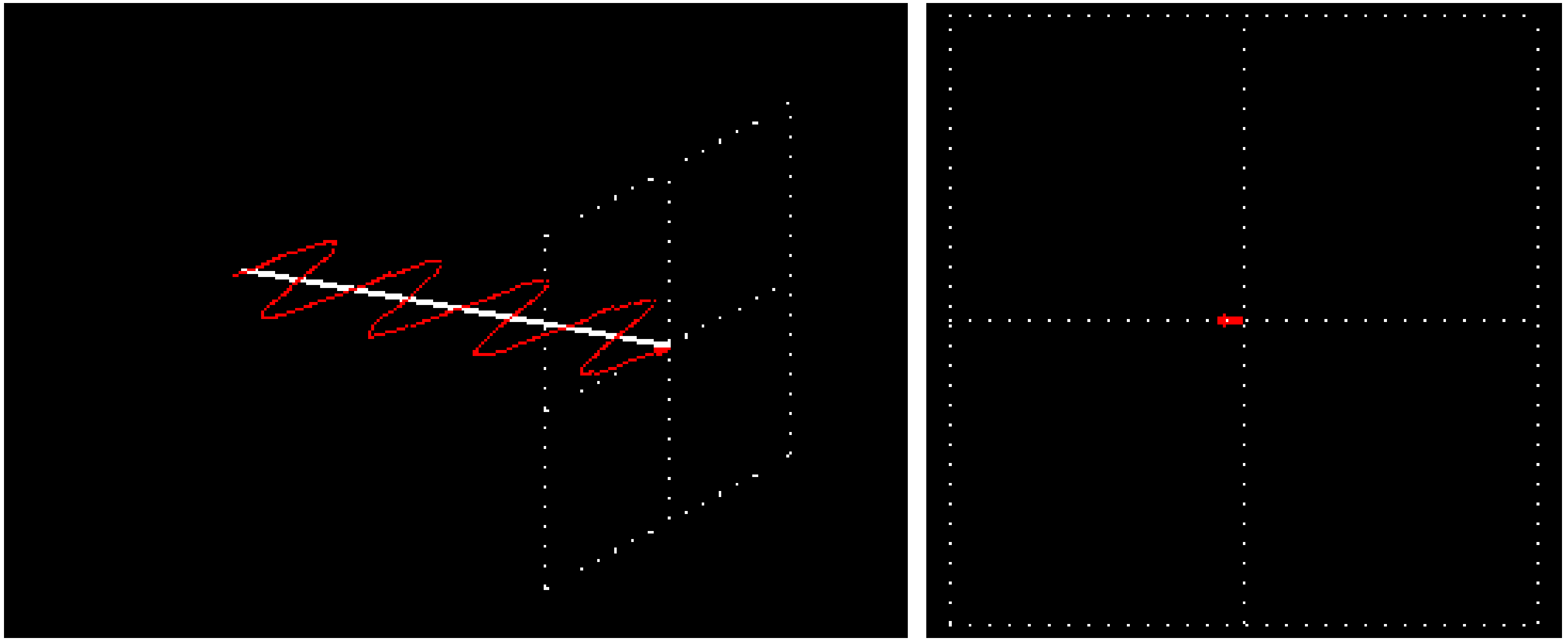




- Why is the detector placed at this position?

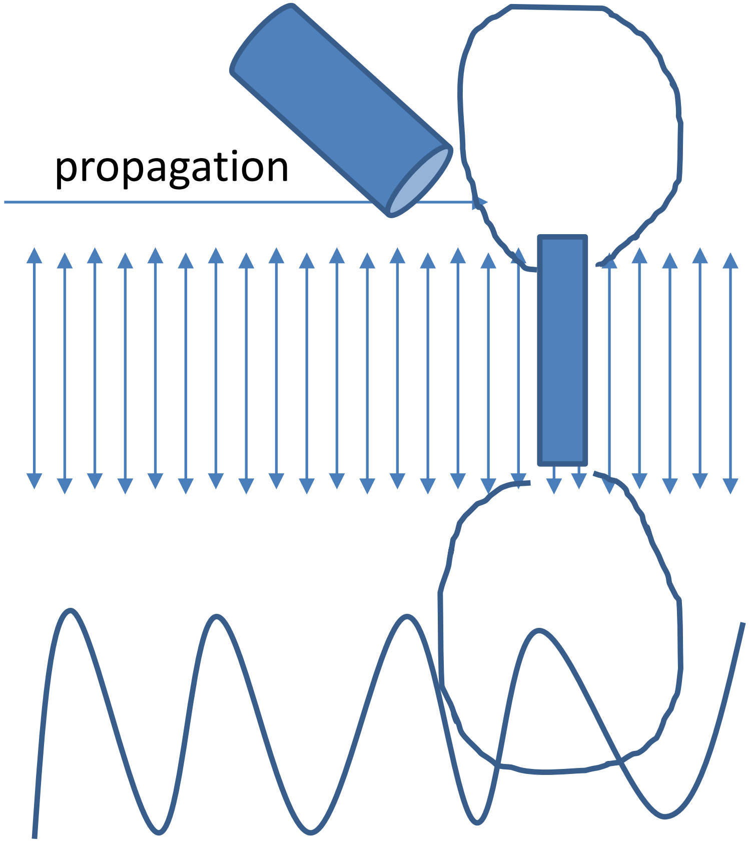
Polarization

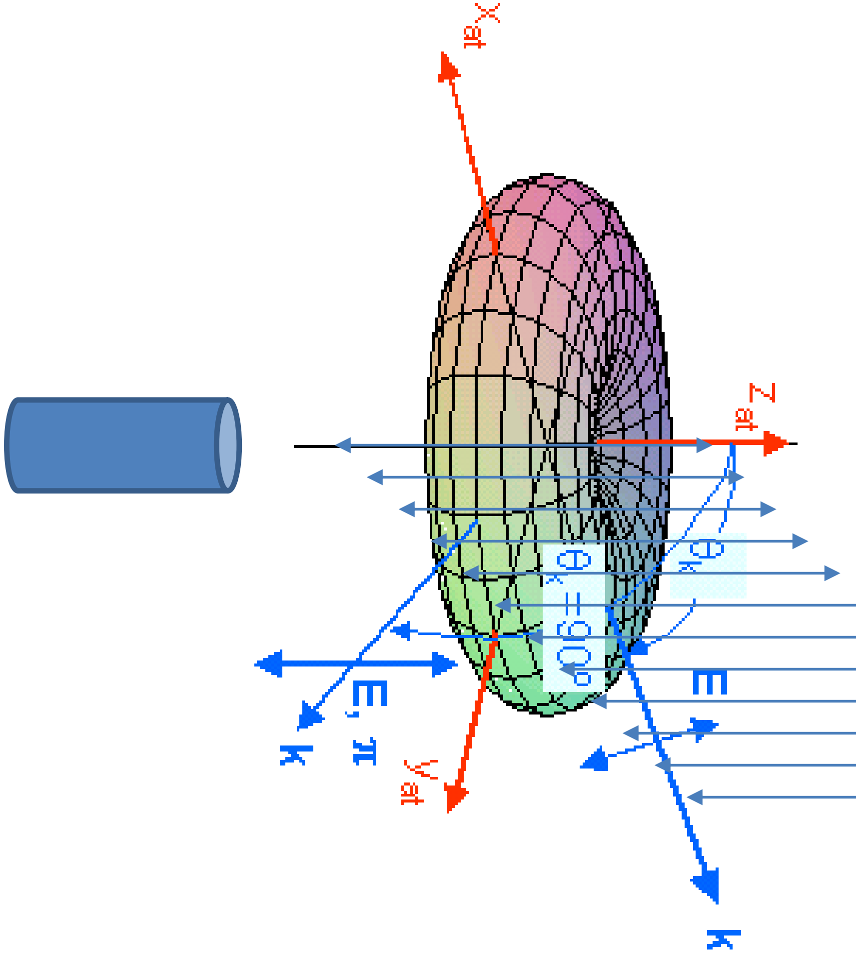
- Horizontal polarization



http://cddemo.szialab.org/

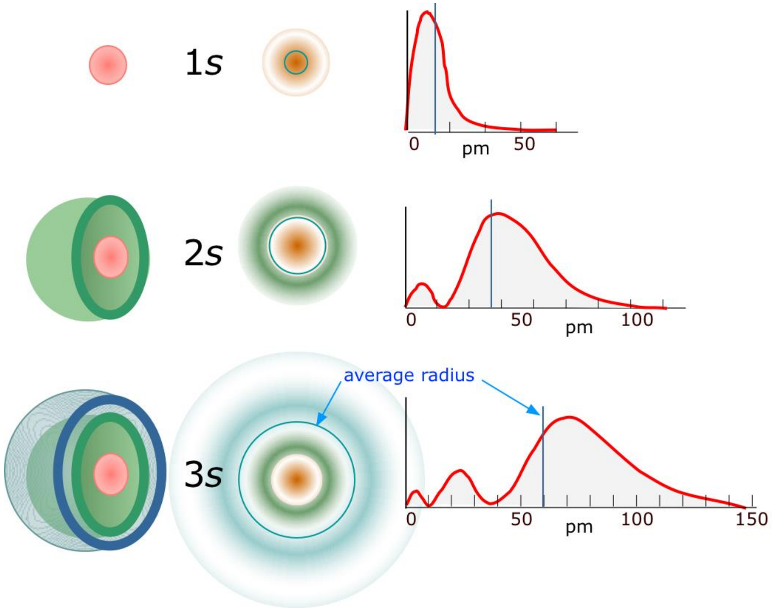
Top view



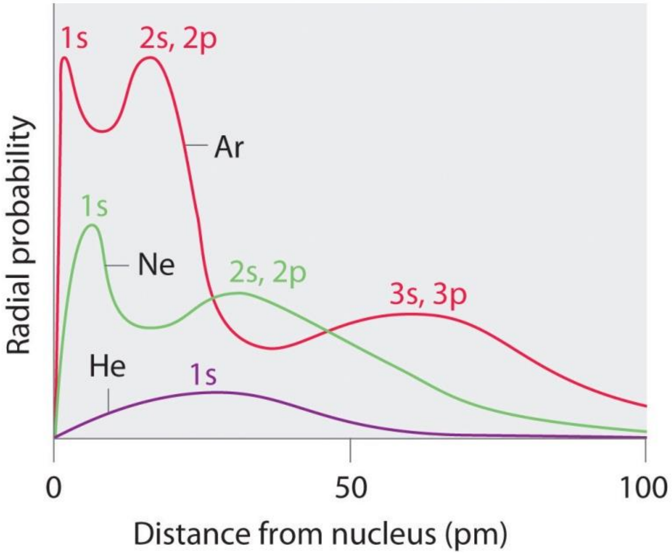


Electronic Structure

- Radial electronic distribution

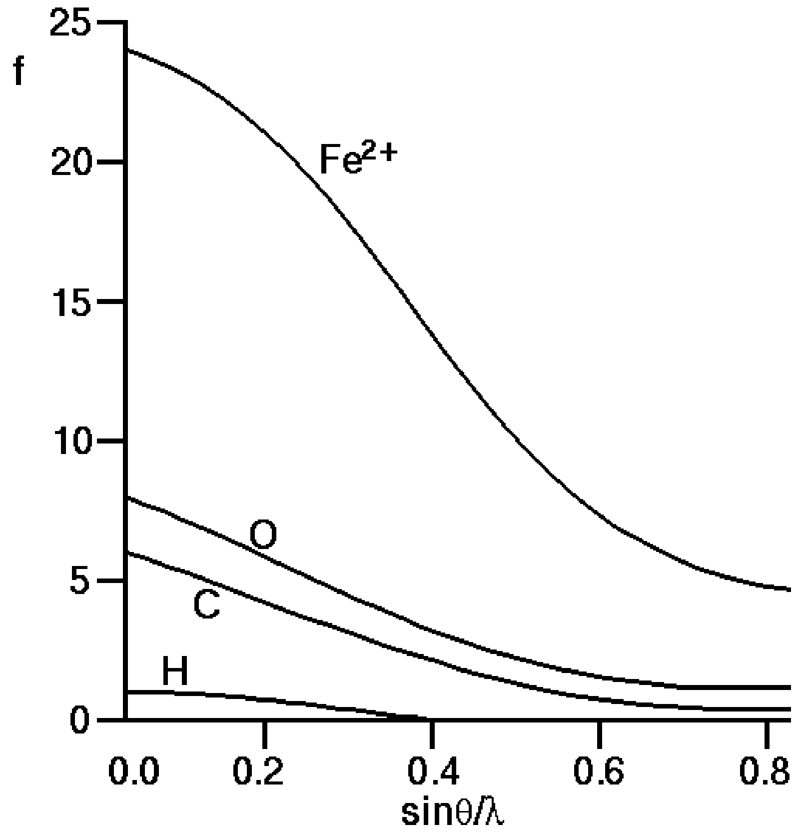


http://chemwiki.ucdavis.edu/@api/deki/files/27872/e730a31a708c5fe85622cbfd31bba9ca.jpg?revision=1



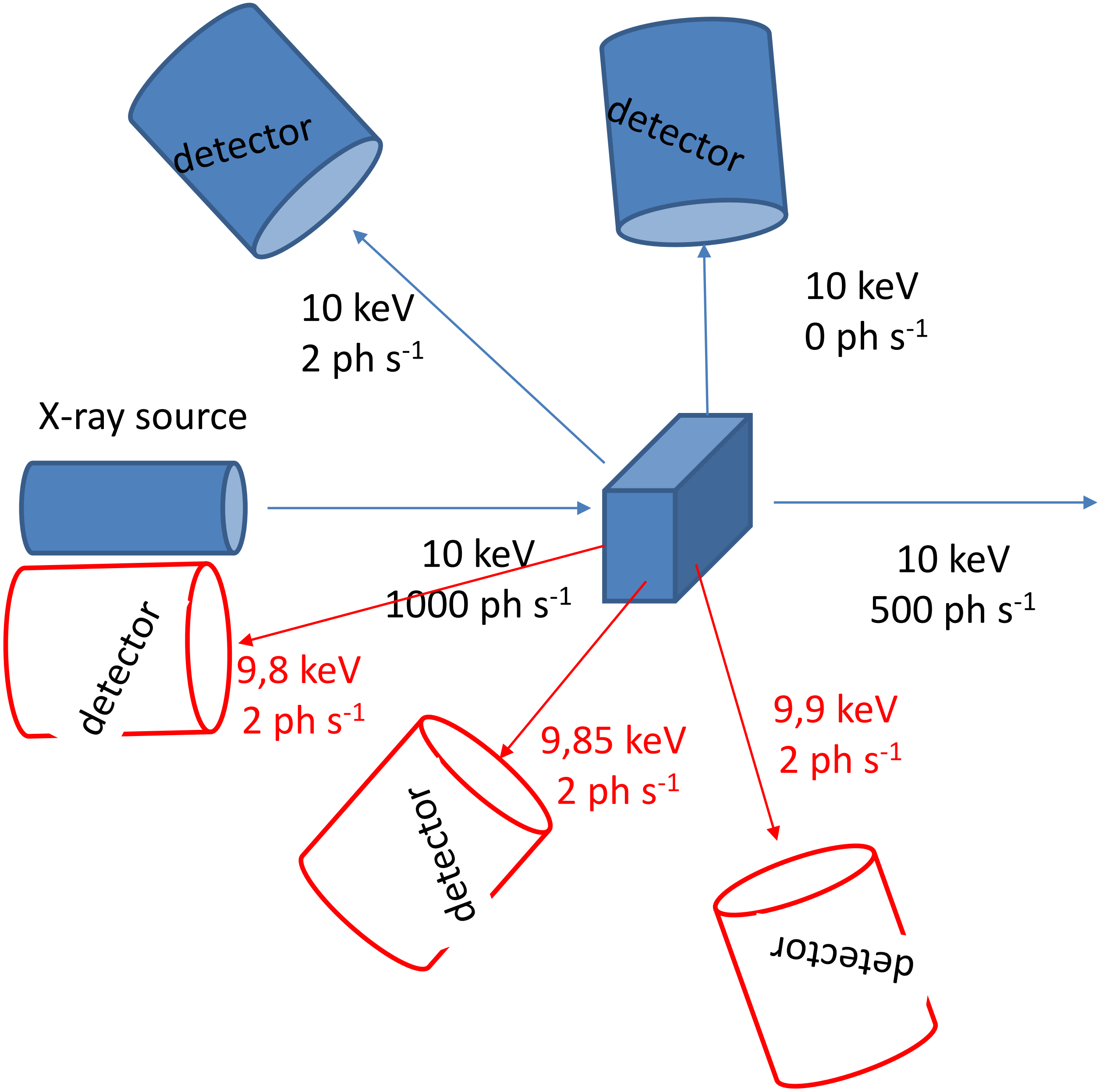
Atomic Scattering Factors

- ☐ Angular dependence of F



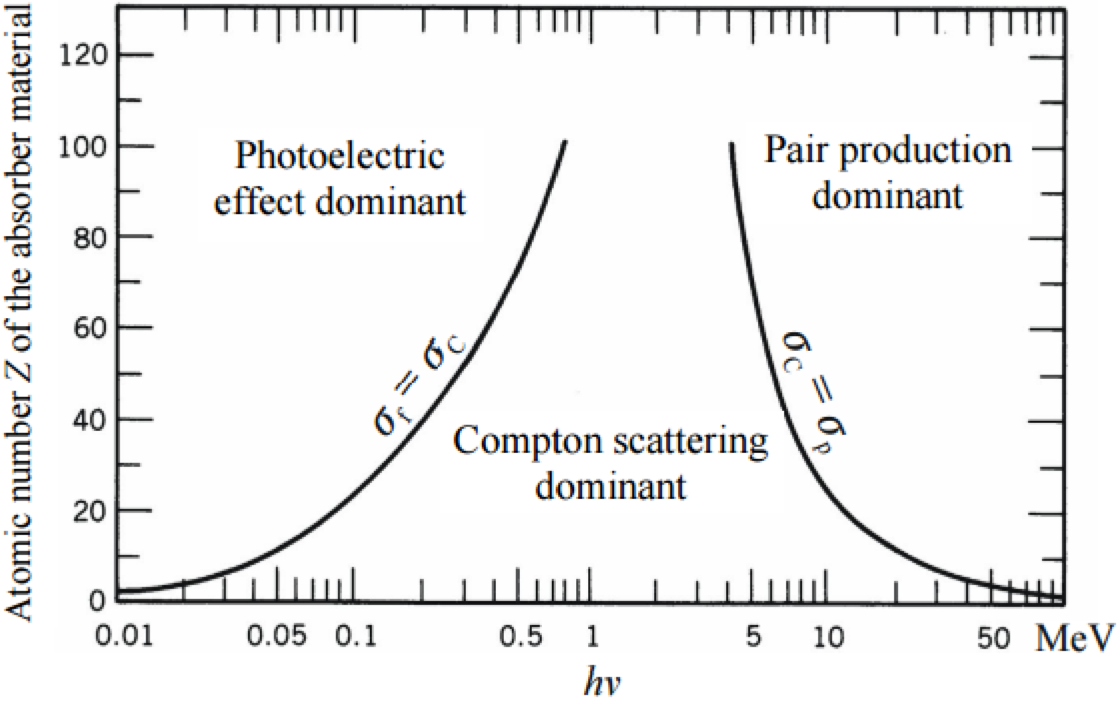
S

5.5 Compton Scattering


detector
detector
10 keV
2 ph s-1
10 keV
0 ph s-1
X-ray source
10 keV
1000 ph s-1
10 keV
500 ph s-1
detector
9,8 keV
2 ph s-1
9,85 keV
2 ph s-1
9,9 keV
2 ph s-1
detector
detector

Compton Scattering is more pronounced at high energies

- ❑ Compton increases as the photoelectric absorption decreases



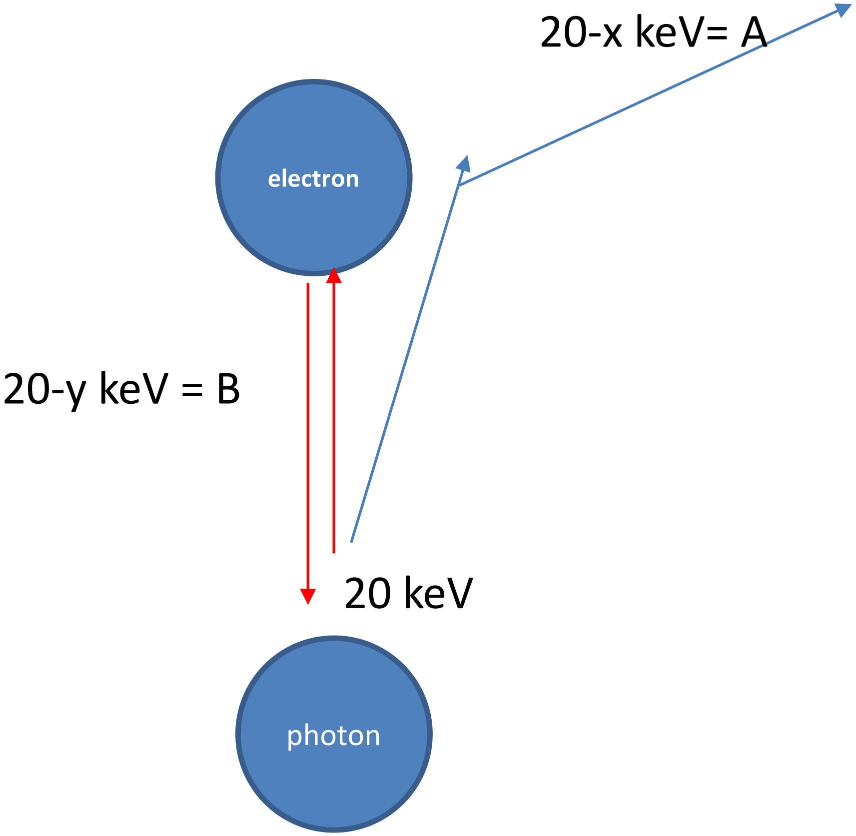
http://www.nuclear-power.net/nuclear-power/reactor-physics/interaction-radiation-matter/interaction-gamma-radiation-matter/gamma-ray-attenuation/

A > B

A=B

A < B

x<y



20-x keV= A

electron

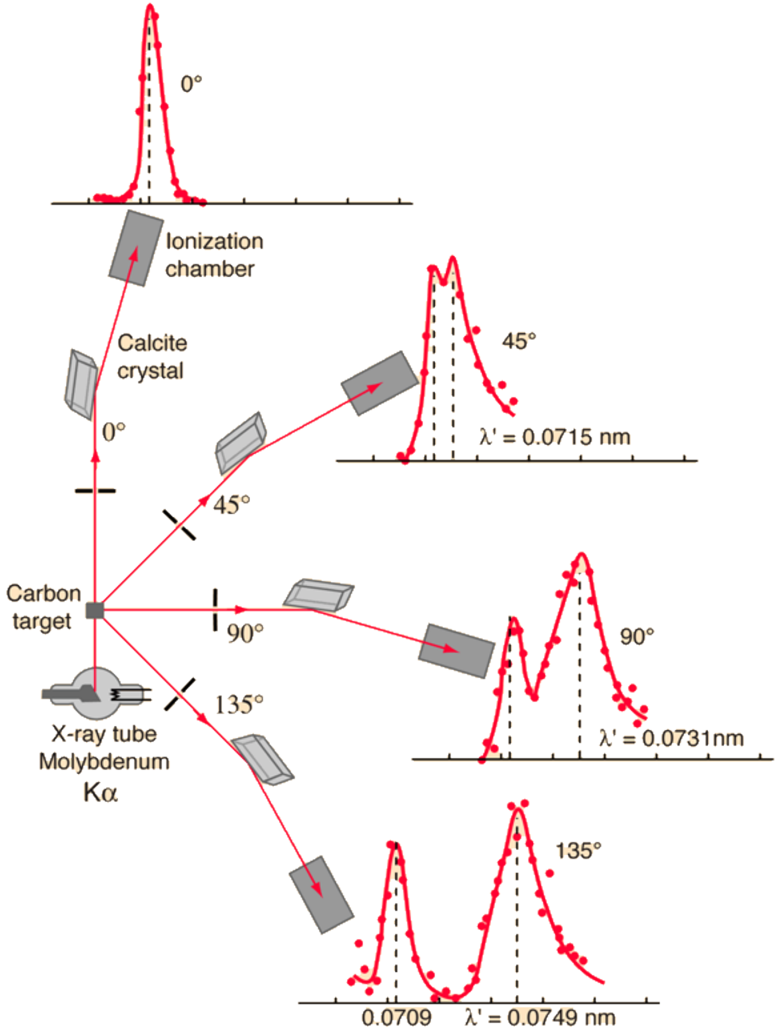
20-y keV = B

20 keV

photon

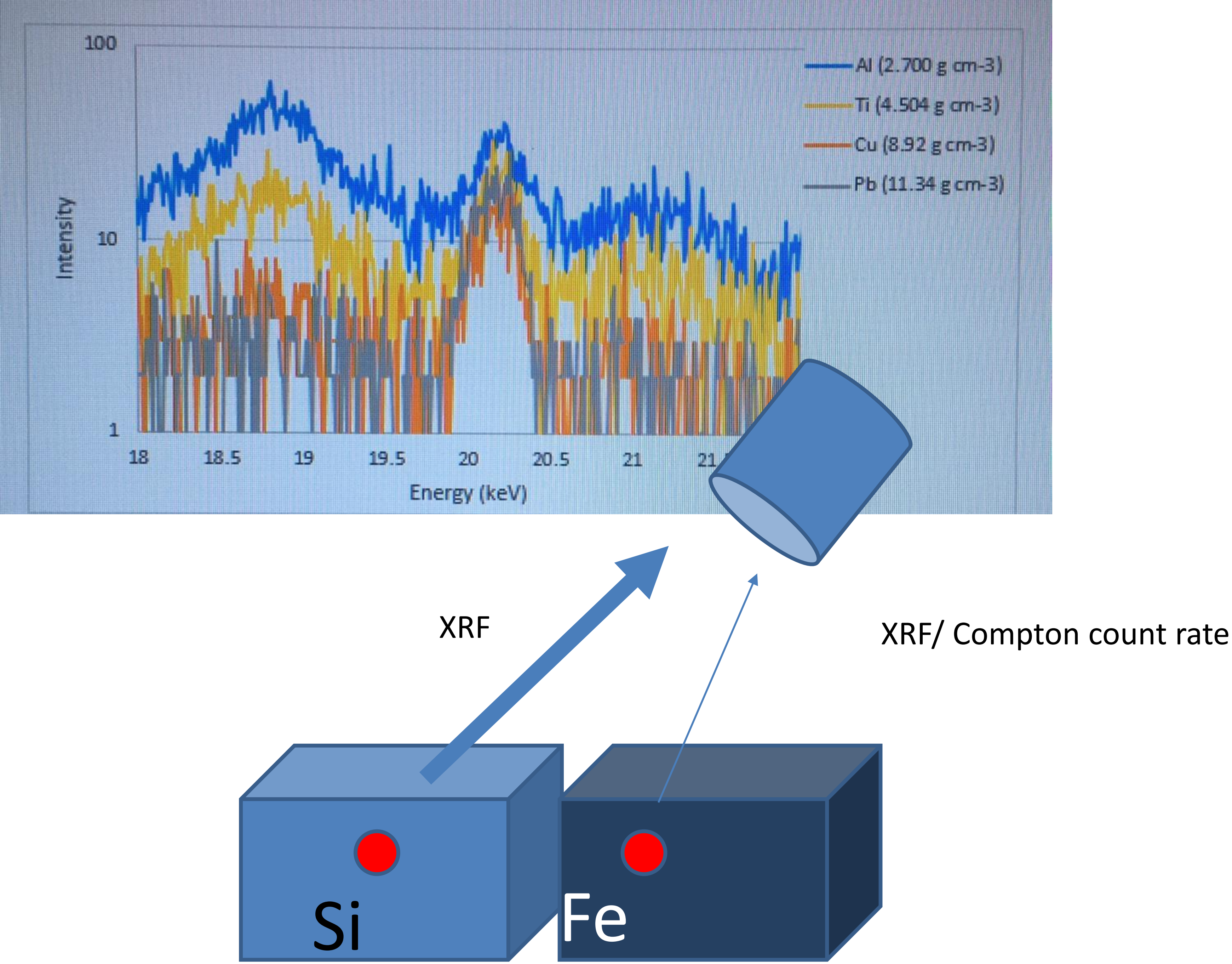
Compton Scattering

- angle dependence



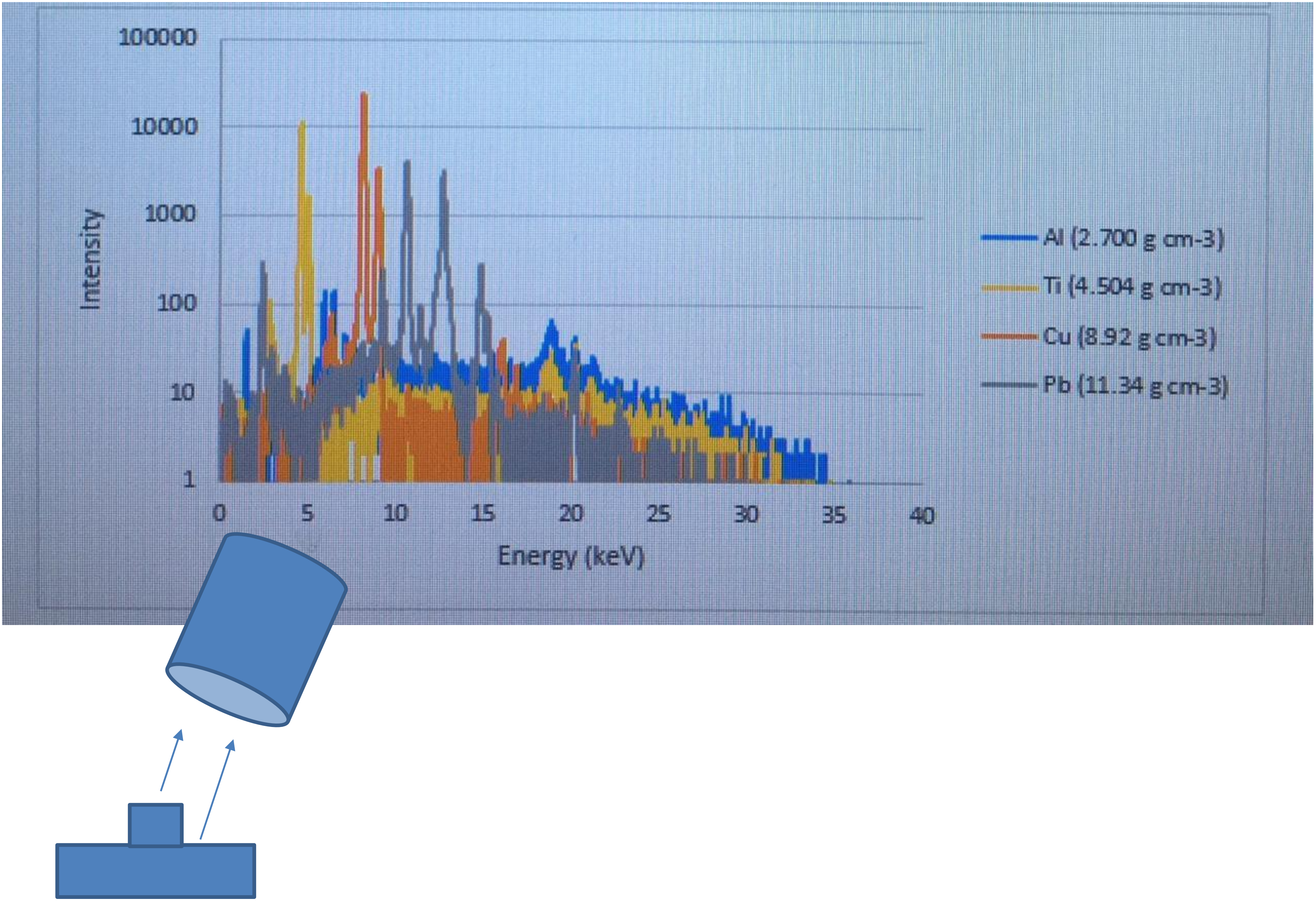
http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/compton.html#c1

- Ei= 20200 eV @45º Ef=19988 eV
- Ei=20220 eV @ 90º Ef= 19450 eV
- Ei= 20200 eV @180º Ef= 18737 eV

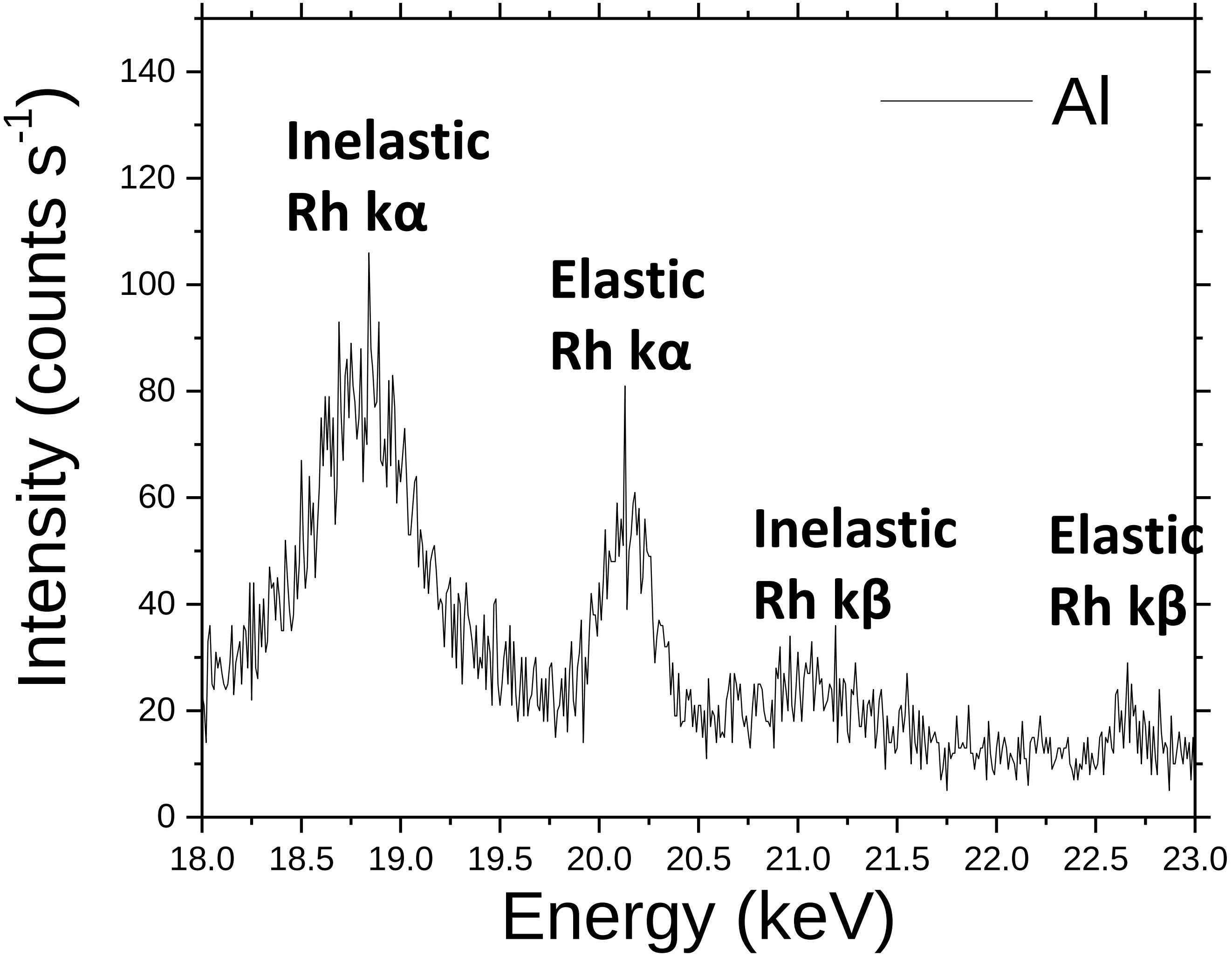


XRF

XRF/ Compton count rate

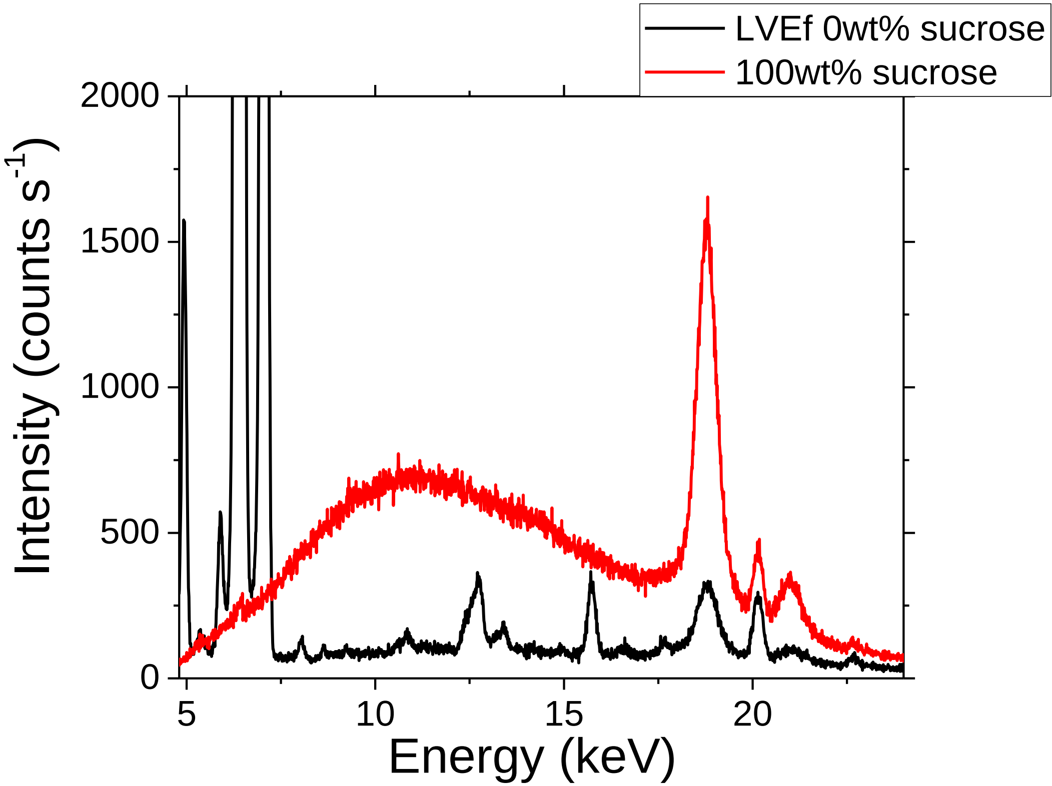

100000
10000
1000
100
10
1
Intensity
0
5
10
15
20
25
30
35
40
Energy (keV)
Al (2.700 g cm-3)
Ti (4.504 g cm-3)
Cu (8.92 g cm-3)
Pb (11.34 g cm-3)

Rh K Compton Scattering



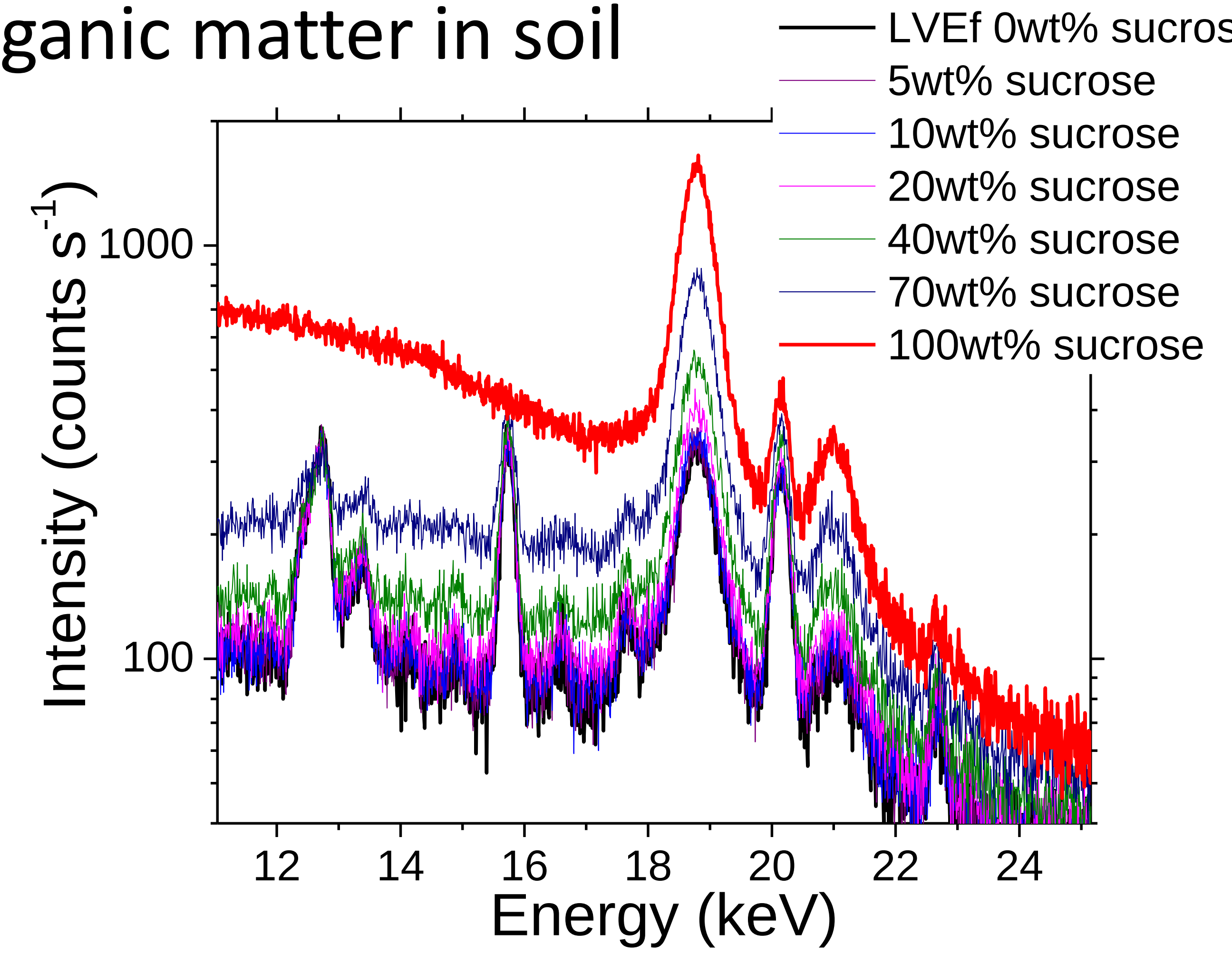
Compton scattering from light and heavy samples

- ❑ Black: soil sample
- ❑ Red: sucrose sample



Compton Scattering

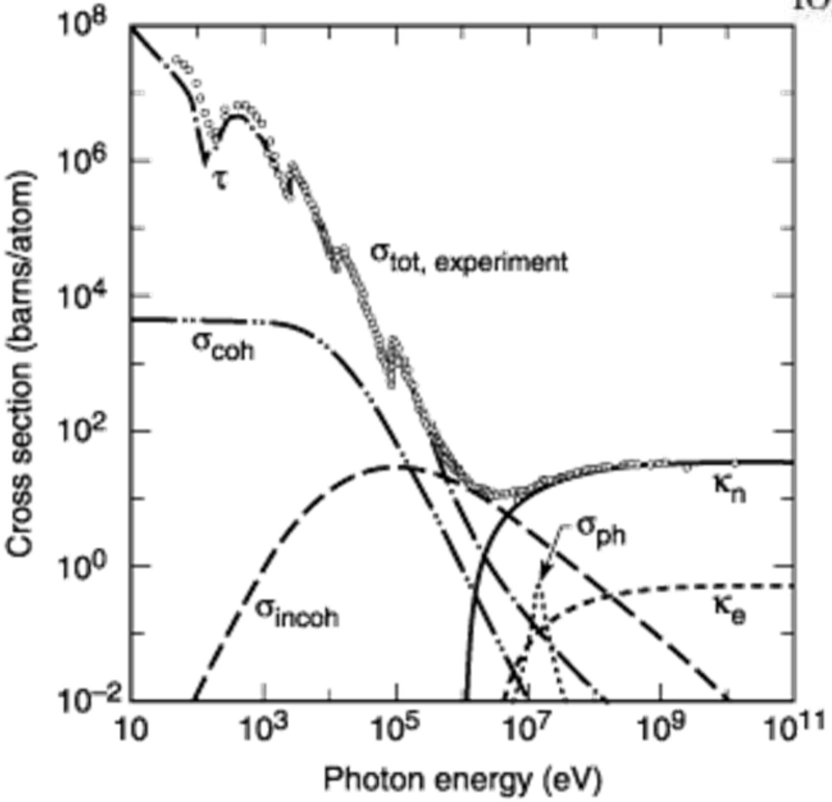
- ☐ Compton response to increasing organic matter in soil

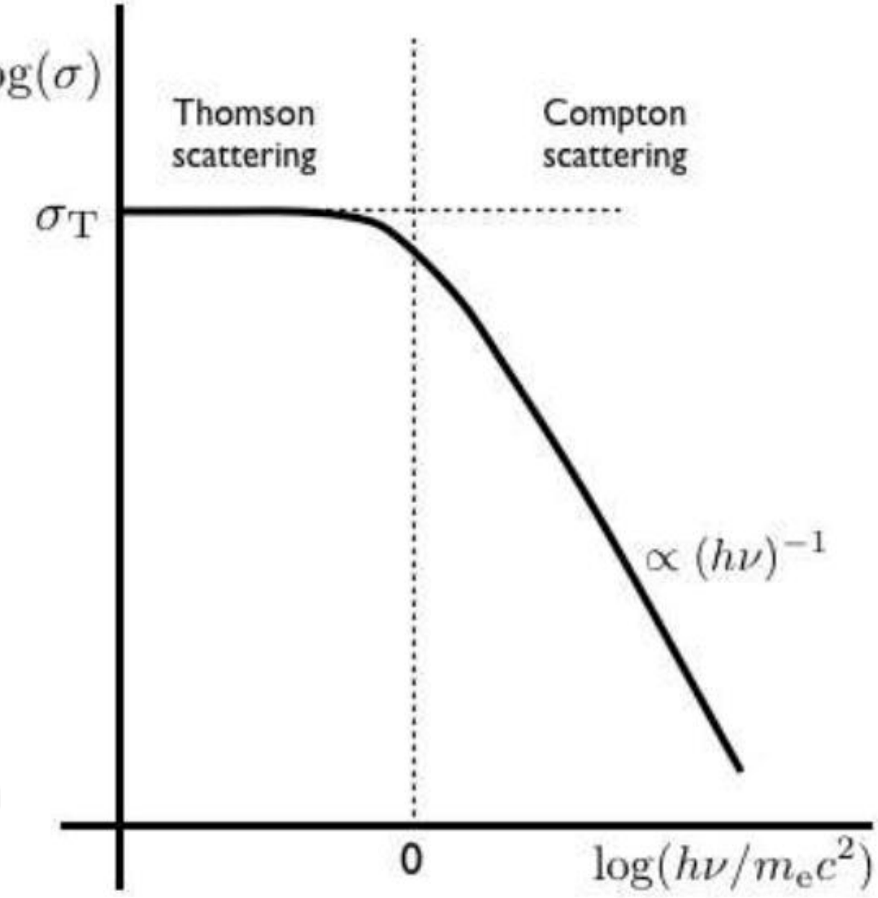


Exploring the competion between the process

The Compton vs Thomson Scattering

- ❑ Compton scattering is quantum mechanical process



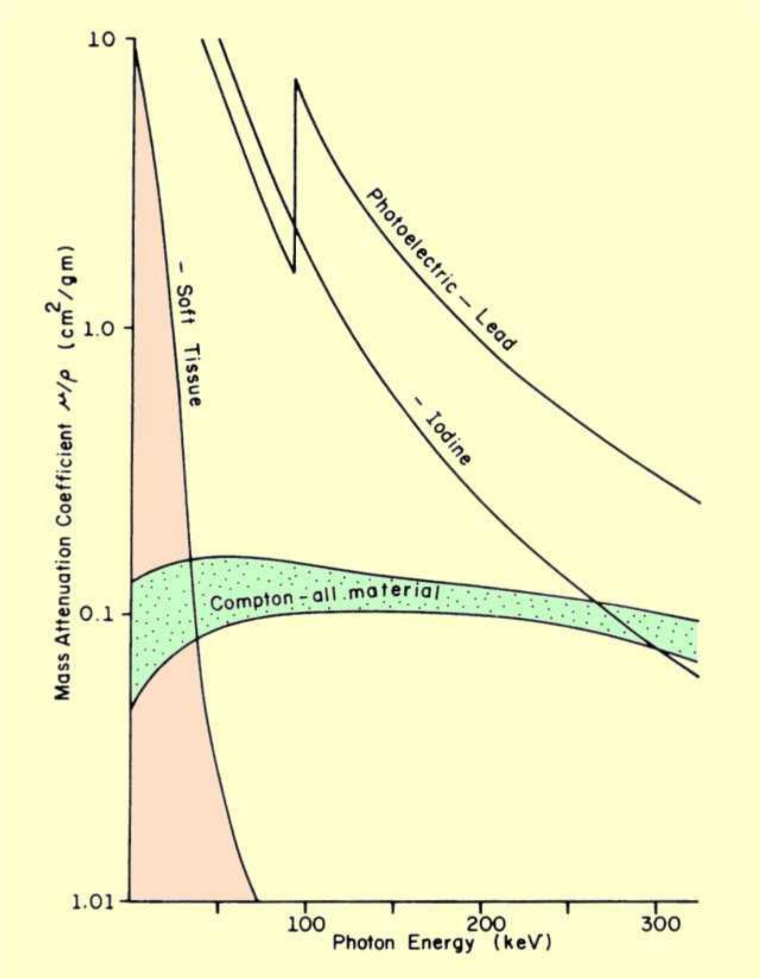


$5*10^5$ (eV)

http://www.astro.yale.edu/vdbosch/astro320_summary23.pdf

- The reason why light elements scatters more Rh Kα Compton is because it stops absorbing!

- For each energy there is a probability that one of several phenomena takes place



http://www.sprawls.org/ppmi2/INTERACT/#Compton Rates