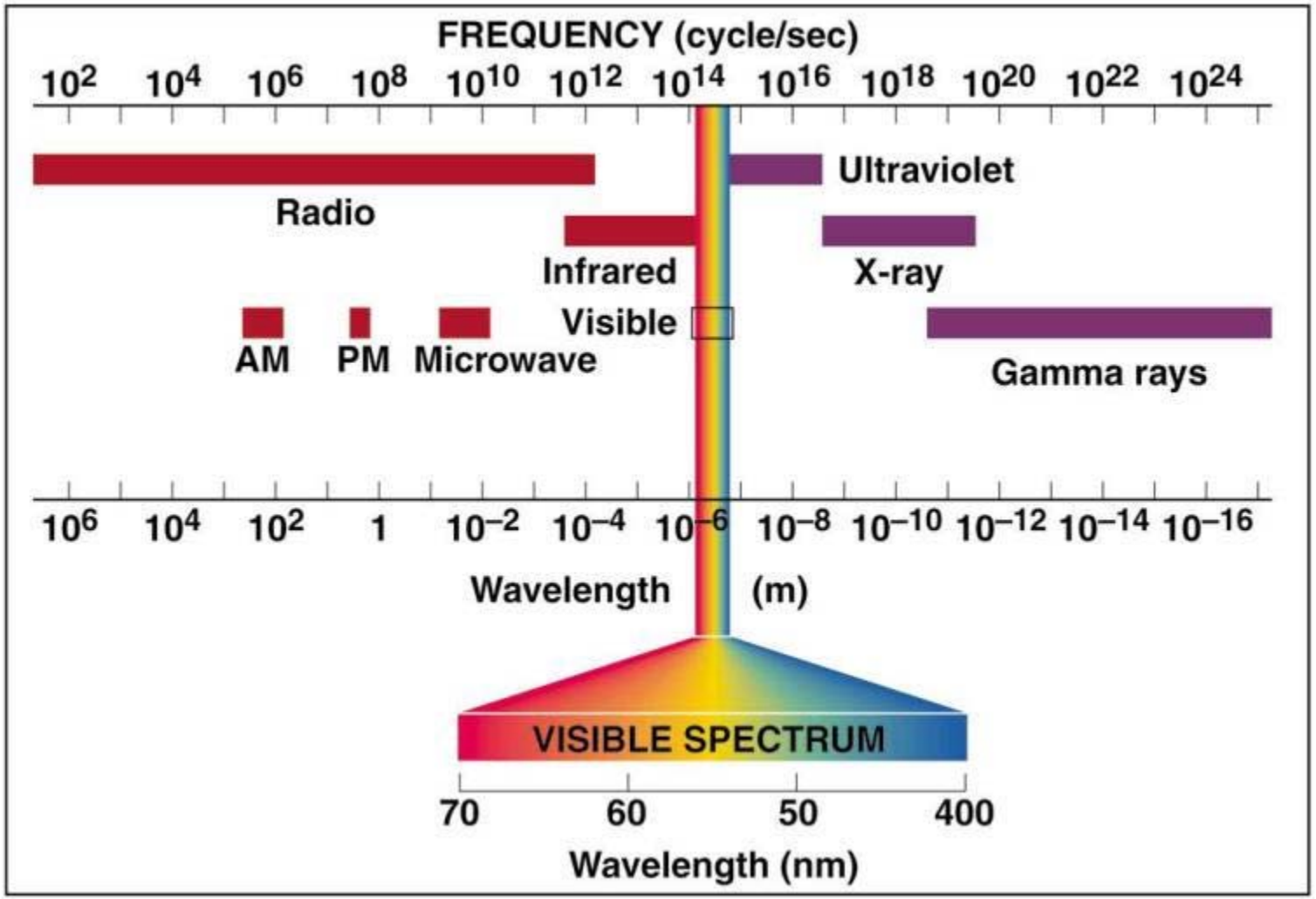

FREQUENCY (cycle/sec)
10^2 10^4 10^6 10^8 10^{10} 10^{12} 10^{14} 10^{16} 10^{18} 10^{20} 10^{22} 10^{24}
Radio
Ultraviolet
Infrared
X-ray
AM
PM
Microwave
Visible
Gamma rays
10^6 10^4 10^2 1 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14} 10^{-16}
Wavelength (m)
VISIBLE SPECTRUM
70 60 50 400
Wavelength (nm)

Interferometer

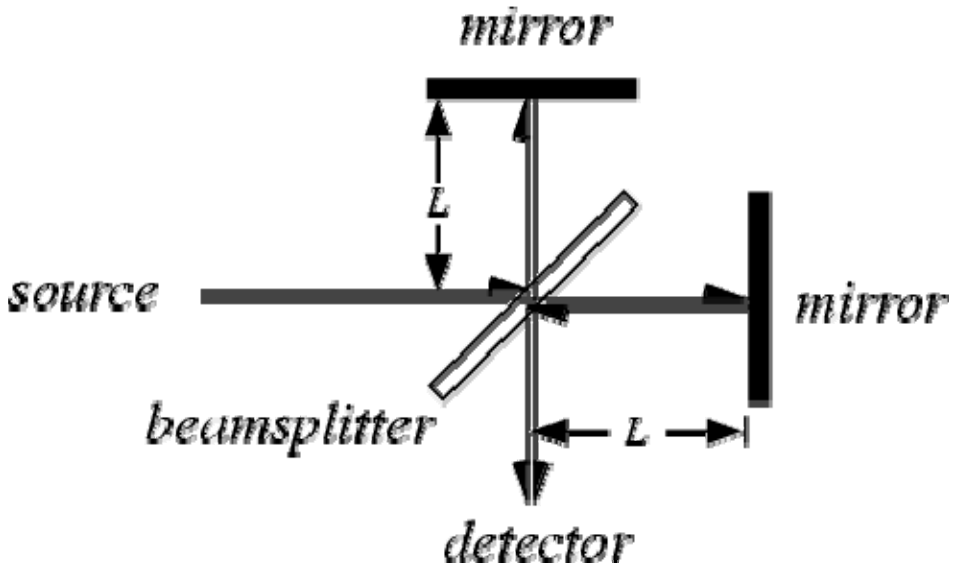
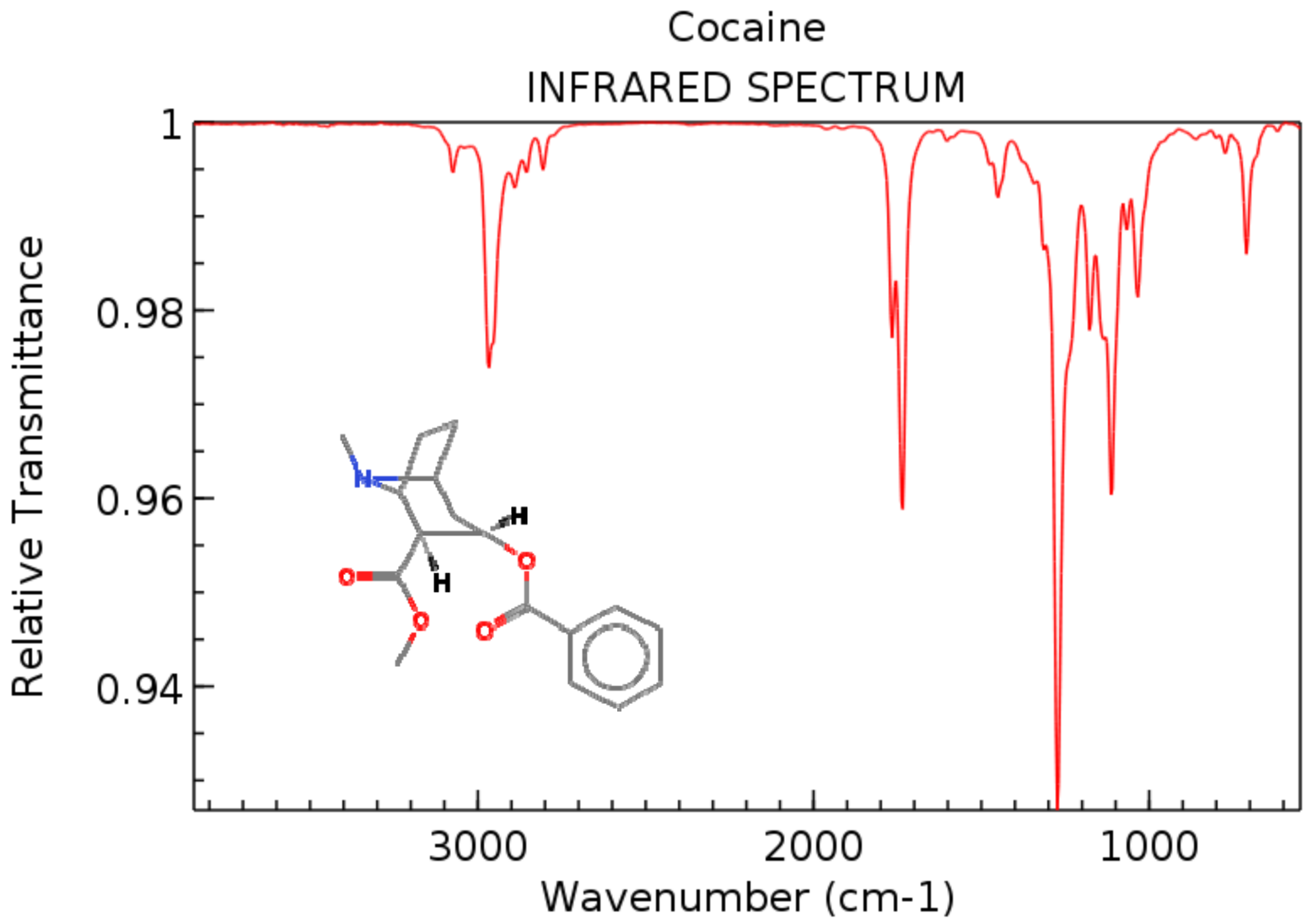


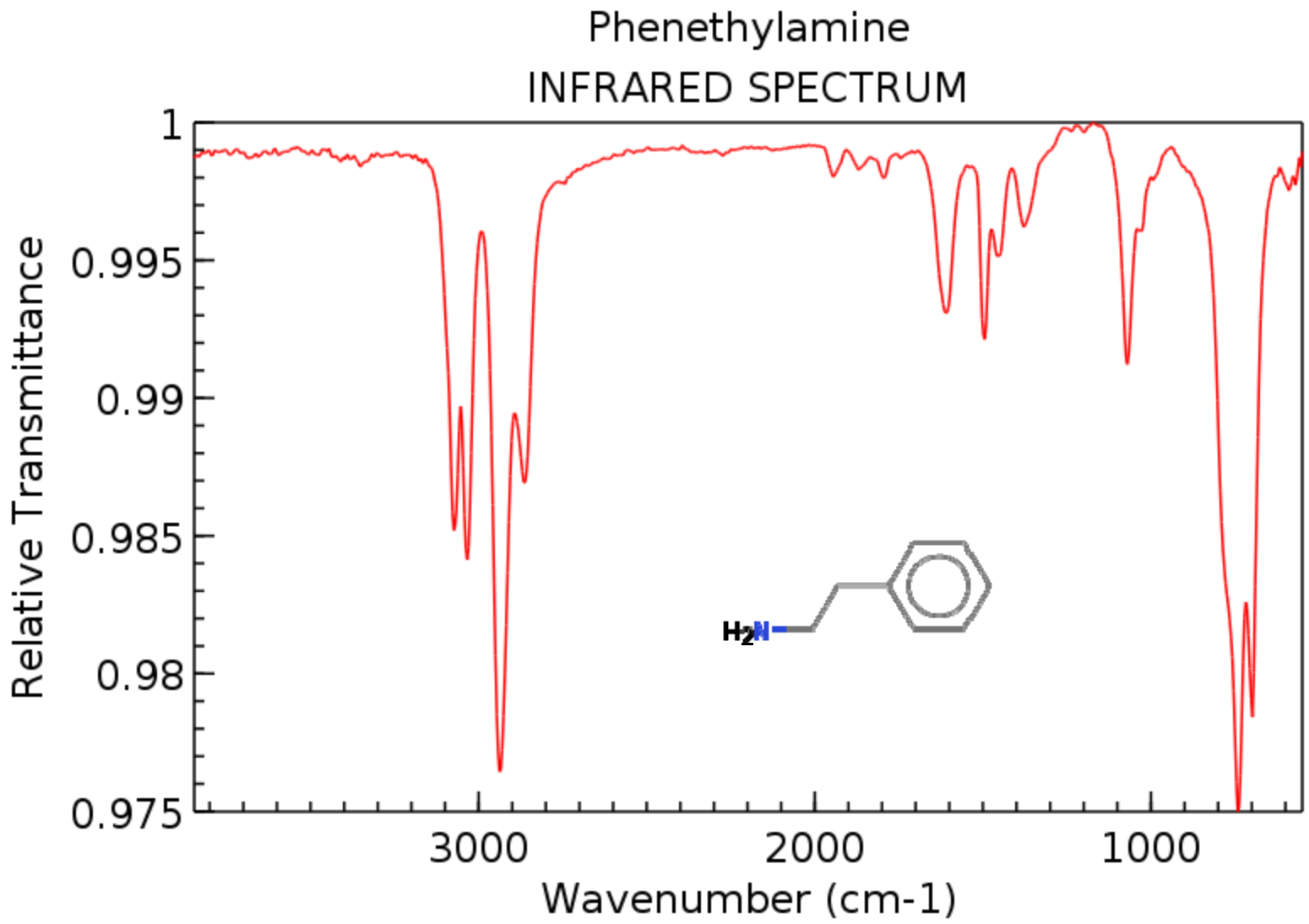
Table 6.3 Typical bond-stretching and angle-bending group vibration wavenumbers ω

Bond-stretching		Bond-stretching		Angle-bending	
Group	ω/cm^{-1}	Group	ω/cm^{-1}	Group	ω/cm^{-1}
≡C–H	3300	–C≡N	2100	≡C–H	700
=C(H)–	3020	>C–F	1100	=C(H)–	1100
except: O=C(H)–	2800	>C–Cl	650	–C(H)–H	1000
>C–H	2960	>C–Br	560	>C(H)–	1450
–C≡C–	2050	>Cl–I	500	C≡C–C	300
>C=C<	1650	–O–H	3600[a]		
>C–C<	900	>N–H	3350		
>Si–Si<	430	>P=O	1295		
>C=O	1700	>S=O	1310		

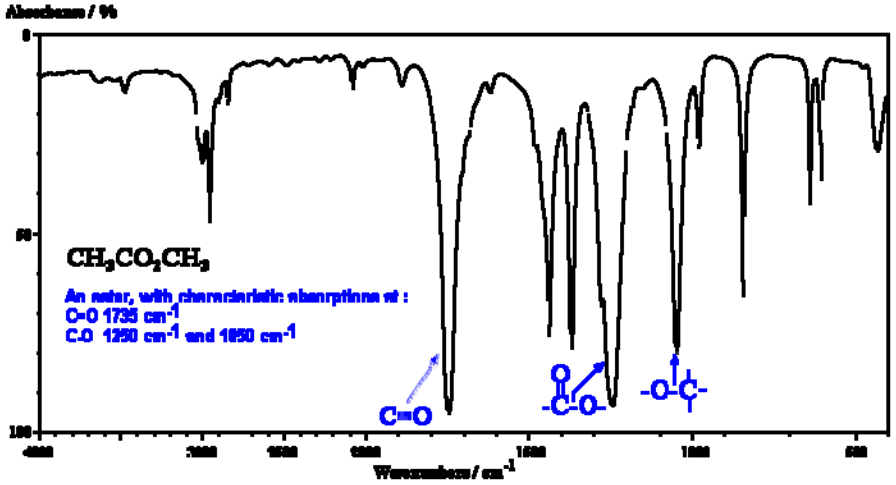
[a] May be reduced in a condensed phase by hydrogen bonding.

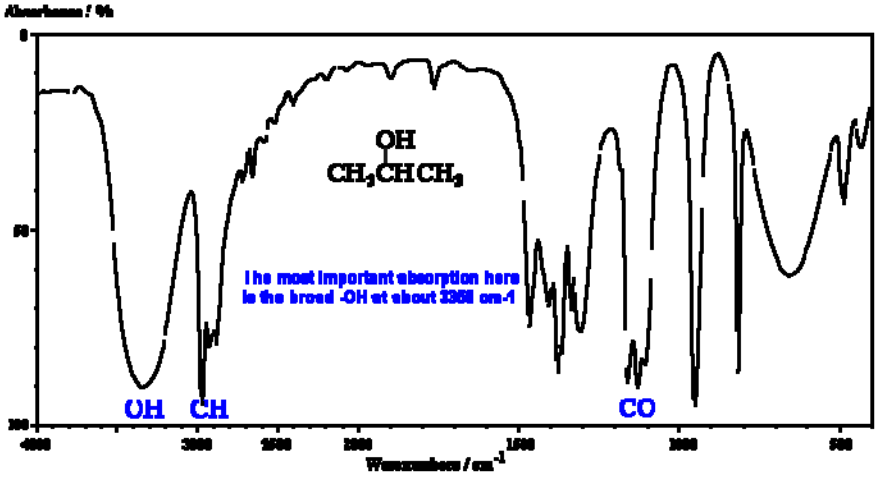


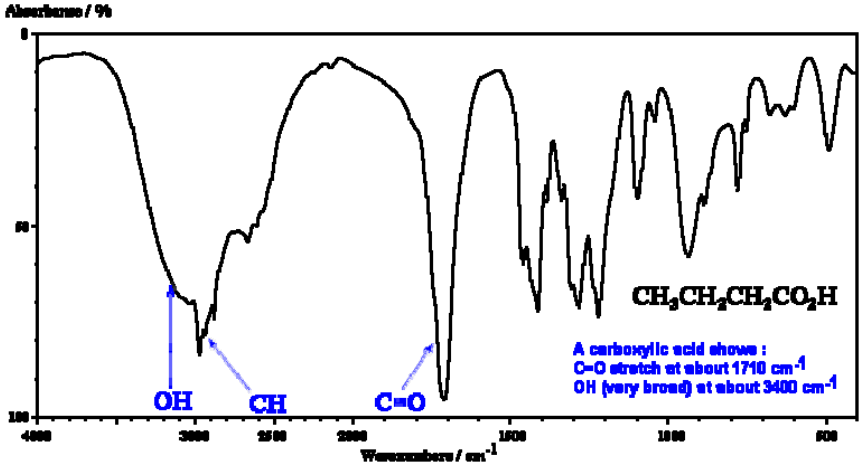
NIST Chemistry WebBook (http://webbook.nist.gov/chemistry)

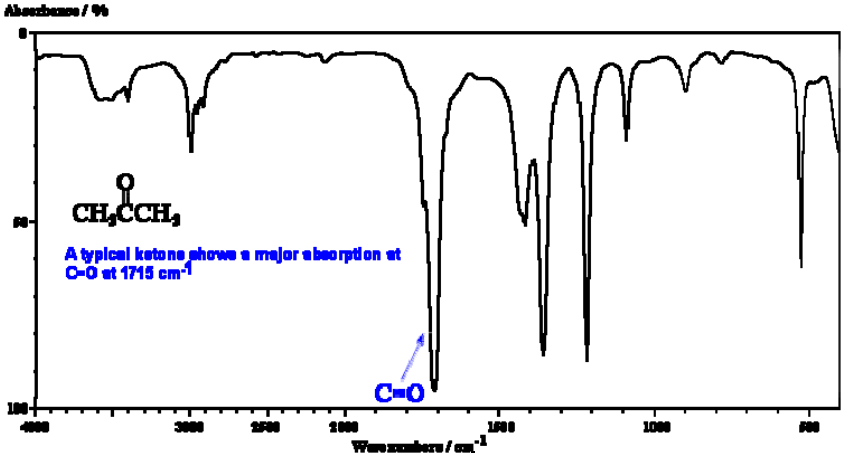


NIST Chemistry WebBook (http://webbook.nist.gov/chemistry)

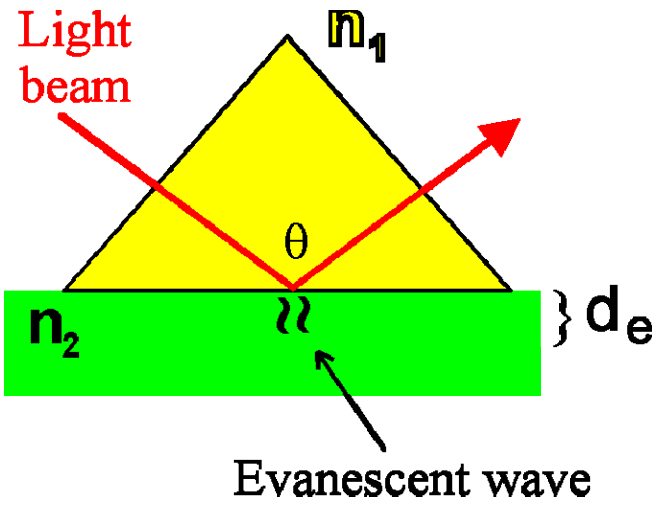

Absorbance / %
100
50
0
4000
3000
2500
2000
1500
1000
500
Wavenumbers / cm-1
CH3CO2CH3
An ester, with characteristic absorptions at :
C=O 1735 cm-1
C-O 1250 cm-1 and 1050 cm-1
C=O
-C-O-
-O-C-

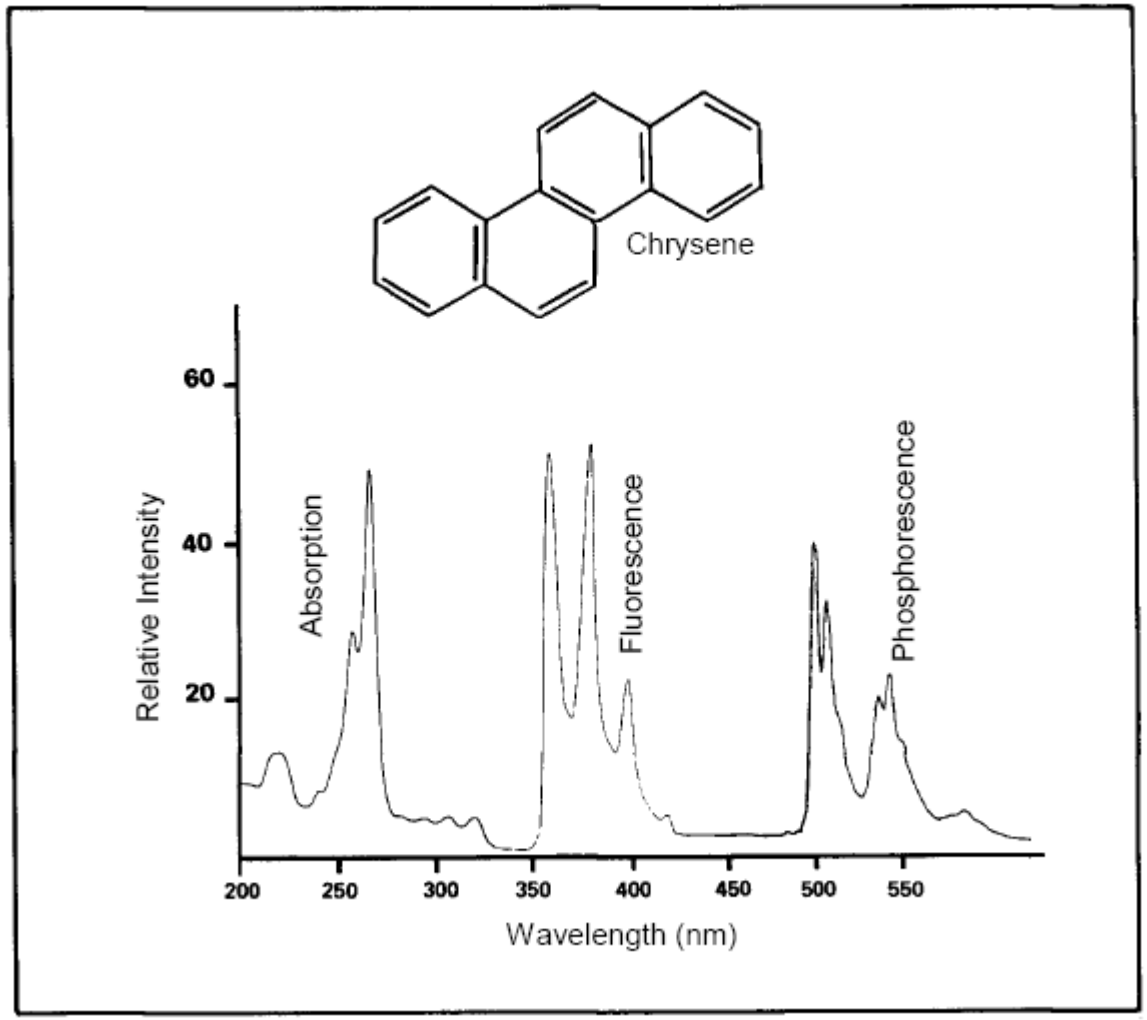

Absorbance / %
100
50
0
4000
3000
2500
2000
1500
1000
500
Wavenumbers / cm-1
OH
CH3CHCH3
The most important absorption here
is the broad -OH at about 3350 cm-1
OH
CH
CO


Absorbance / %
100
50
0
4000
3000
2500
2000
1500
1000
500
Wavenumbers / cm-1
CH3CH2CH2CO2H
A carboxylic acid shows :
C=O stretch at about 1710 cm-1
OH (very broad) at about 3400 cm-1
OH
CH
C=O

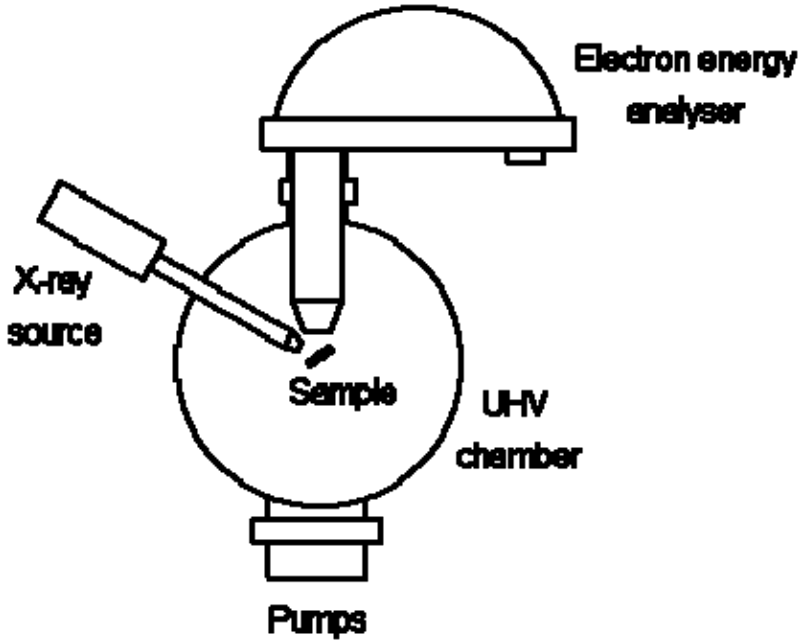

Absorbance / %
100
50
0
4000
3000
2500
2000
1500
1000
500
Wavenumbers / cm-1
CH3CCH3
O
A typical ketone shows a major absorption at
C=O at 1715 cm-1
C=O

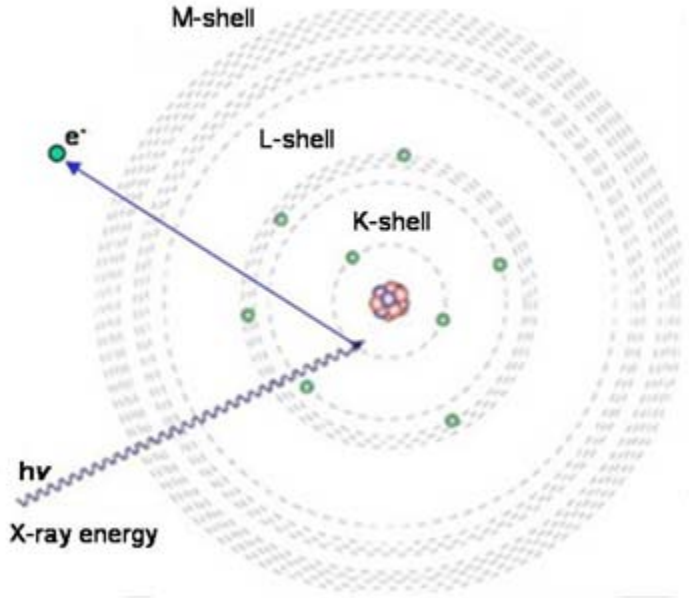
ATR




Chrysene
Relative Intensity
60
40
20
Absorption
Fluorescence
Phosphorescence
200
250
300
350
400
450
500
550
Wavelength (nm)

Photoelectron Spectroscopy





Fundamental XPS Data from Pure Elements, Pure Oxides, and Chemical Compounds

C(1s) BE = 285.0 eV
Charge Referencing

Atomic Number of Element
Abbreviation for Element
Al (2p3) BE of Al° under Native Oxide
Al (2p3) FWHM of Al° under Native Oxide
C (1s) BE of Hydrocarbons Captured by Ion Etched Al°
Reliable Reference BE for Ion Etched, Pure Al°
Al (2p3) FWHM of Ion Etched , Pure Al°

13 Al 2p3	
Al°	Al2O3
72.9 (0.62)	74.3 (1.41)
284.7	285.0
72.82 (0.41)	531.1 (1.56)

Main XPS Signal for Element of Interest
Most Common Oxide or Chemical Compound of Element
Al (2p3) BE of Major Oxide Species in Pure Oxide
Al (2p3) FWHM of Major Oxide Species in Pure Oxide
C (1s) BE Defined to be at 285.0 eV
O (1s) BE of Major Oxygen Species in Pure Oxide
O (1s) FWHM of Major Oxygen Species in Pure Oxide

All non-conductive materials were referenced to adventitious hydrocarbon with C (1s) BE at 285.0eV.
Energy resolution settings for pure oxide data gave FWHM <0.75 eV for Ag (3d5) of ion etched Ag°.
All non-conductors were analyzed with the Flood-Gun Mesh-Screen 0.5-1.0 mm above the specimen.
C (1s) BEs for "hydrocarbons" on elements were collected from carbon captured by ion etched elements.
Carbon from the cryo-pumped vacuum (3x10(-9) torr) was analyzed >10 hours after ion etching.
Energy resolution settings for ion etched elements gave FWHM <0.50 eV forAg (3d5) of ion etched Ag°.
Calibration was: Cu (2p3) at 932.67 ±0.05 eV, Cu (3s) at 122.45 ±0.05 eV, and Au(4f7) at 83.98 eV.

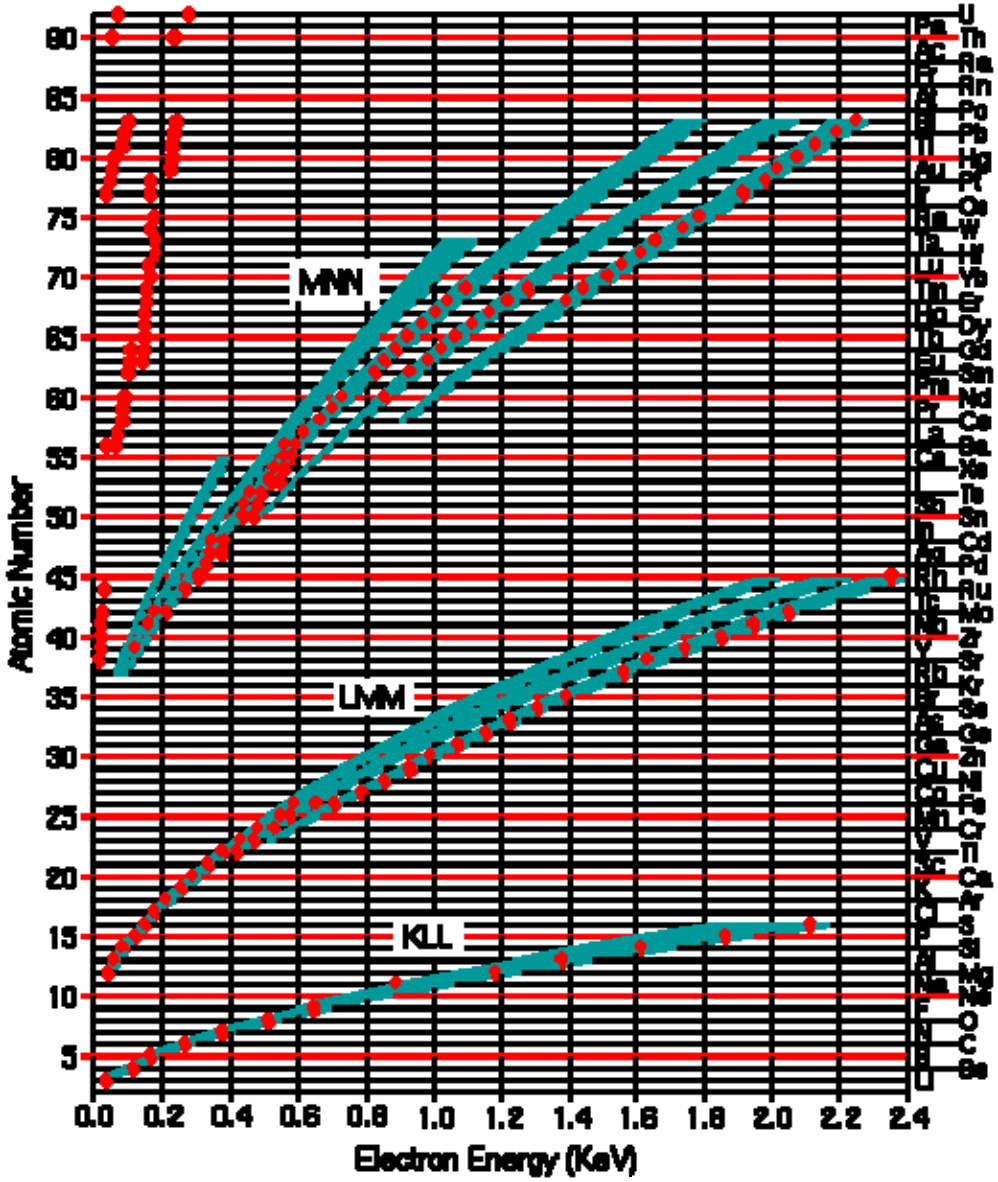
The FWHM and BE values presented in this table were all obtained by one scientist using two SSI XPS systems, which yield a theoretical energy resolution limit of about 0.1 eV and were equipped with monochromatic Aluminum X-ray sources which have a theoretical energy resolution limit of about 0.16 eV. The BEs for the ion etched elements can be used as reliable secondary energy reference values within a standard deviation of 0.055. All other BE values are <±0.15 eV.

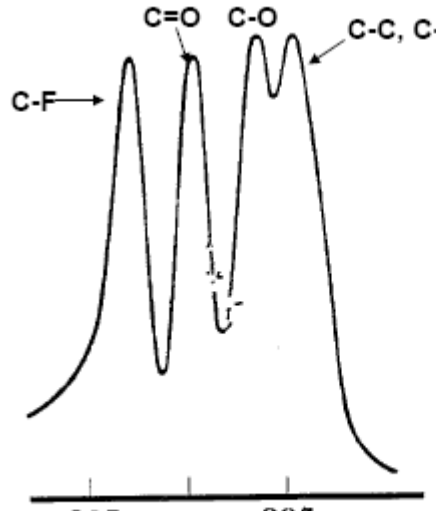
1																		18
1 H 1s H_2° LiH	2											13	14	15	16	17		2 He 1s He+/Be He+/C
3 Li 1s Li° LiOH 54.9 (1.65) 285.0 531.8 (1.6)	4 Be 1s Be° BeO 111.9 113.6 (0.79) (1.73) 286.1 285.0 111.88 531.3 (0.69) (1.47)	3	4	5	6	7	8	9	10	11	12	5 B 1s B° B2O3 187.5 194.0 (0.87) (2.40) 285.2 285.0 187.8 532.5 (1.03) (2.22)	6 C 1s HOPG Black 284.5 284.4 (0.42) (1.04)	7 N 1s Kapton BN 400.9 398.9 (1.31) (1.10) 285.0 285.0 191.3 (1.03)	8 O 1s CuO SiO2 529.7 532.5 (0.98) (1.40) 284.9 285.0 934.0 103.0 (1.42) (1.14)	9 F 1s Teflon CaF2 688.9 685.1 (1.8) (1.53) 285.0 285.0 291.9 348.1 (1.6) (1.6)	10 Ne 1s Ne+/Be Ne+/C
11 Na 1s Na° NaCl 1072.0 (1.40) 285.0 199.3 (1.19)	12 Mg 2p Mg° MgO 49.7 49.5 (0.58) (1.63) 286.5 285.0 49.77 529.8 (0.60) (1.99)											13 Al 2p3 Al° Al2O3 72.9 74.3 (0.62) (1.41) 284.7 285.0 72.82 531.1 (0.41) (1.56)	14 Si 2p3 Si° SiO2 99.8 103.0 (0.57) (1.14) 285.3 285.0 99.35 532.5 (0.45) (1.40)	15 P 2p3 P° InP 130.13 128.8 (0.67) (0.62) 285.0 285.0 444.7 (0.78)	16 S 2p3 S° MoS2 164.0 162.7 (0.72) (0.39) 285.0 229.7 (0.80)	17 Cl 2p3 PVC NaCl 199.8 199.3 (1.7) (1.19) 285.0 285.0 1072.0 (1.40)	18 Ar 2p3 Ar+/Be Ar+/C 242.1 (0.90) 285.0
19 K 2p3 K° KI 293.2 (1.11) 285.0 619.2 (1.30)	20 Ca 2p3 Ca° CaO 346.5 347.1 (?) (1.81) 284.6 285.0 346.5 531.5 (1.07) (1.57)	21 Sc 2p3 Sc° Sc2O3 398.6 401.9 (0.9) (1.27) 285.8 285.0 398.46 530.0 (0.69) (1.33)	22 Ti 2p3 Ti° TiO2 453.8 458.7 (0.90) (1.09) 285.2 285.0 453.95 530.0 (0.62) (1.18)	23 V 2p3 V° V2O5 512.2 517.3 285.0 285.0 512.22 530.2 (0.75) (1.33)	24 Cr 2p3 Cr° Cr2O3 574.2 575.7 (1.05) (1.20) 284.6 285.0 574.37 530.1 (0.89) (1.24)	25 Mn 2p3 Mn° MnO2 638.7 641.5 (1.00) (1.12) 286.4 285.0 638.74 529.5 (0.89) (1.02)	26 Fe 2p3 Fe° Fe2O3 706.6 709.8 (0.90) (1.32) 284.9 285.0 706.78 532.9 (0.99) (1.05)	27 Co 2p3 Co° Co3O4 778.1 779.5 (0.99) (1.39) 284.9 285.0 778.26 530.1 (0.85) (1.00)	28 Ni 2p3 Ni° NiO 852.6 853.8 (1.14) (1.42) 284.8 285.0 852.65 529.4 (1.02) (1.03)	29 Cu 2p3 Cu° Cu2O 932.7 932.5 (1.22) (1.10) 284.6 285.0 932.68 530.5 (0.92) (1.01)	30 Zn 2p3 Zn° ZnO 1021.8 1021.7 (1.10) (1.50) 284.8 285.0 1021.76 530.5 (0.97) (1.11)	31 Ga 3d5 Ga° Ga2O3 18.7 20.7 (0.70) (1.37) 285.0 285.0 18.5 531.3 (0.60) (1.51)	32 Ge 3d5 Ge° GeO2 29.3 33.2 (0.68) (1.49) 285.0 285.0 29.28 532.2 (0.64) (1.40)	33 As 3d5 As° As2O3 41.8 45.1 (0.67) (1.26) 284.5 285.0 41.69 532.0 (0.67) (1.41)	34 Se 3d5 Se° SeOx 54.8 59.3 (0.76) (1.09) 284.2 285.0 54.90 532.6 (0.78)	35 Br 3d5 KBr 68.8 (0.92) 285.0 293.0 (1.31)	36 Kr 3d5 Kr+/Be Kr+/C 86.94 (0.79) 285.0
37 Rb 3d5 Rb° RbOAc 109.7 (1.40) 285.0 530.9 (1.6)	38 Sr 3d5 Sr° SrCO3 133.7 (1.63) 285.0 531.5 (1.9)	39 Y 3d5 Y° Y2O3 155.9 156.6 (0.80) (1.25) 286.0 285.0 155.92 531.0 (0.62) (1.30)	40 Zr 3d5 Zr° ZrO2 179.0 182.4 (0.90) (1.18) 285.3 285.0 178.80 530.3 (0.63) (1.39)	41 Nb 3d5 Nb° Nb2O5 202.1 207.4 (0.78) (1.14) 285.0 285.0 202.35 530.4 (0.57) (1.36)	42 Mo 3d5 Mo° MoO3 227.8 233.1 (0.66) (1.05) 285.4 285.0 227.94 531.0 (0.57) (1.20)	43 Tc 3d5 Tc°	44 Ru 3d5 Ru° RuO2 280.0 281.1 (0.67) (0.79) --- 285.0 280.11 529.7 (0.59) (0.95)	45 Rh 3d5 Rh° Rh2O3 307.2 308.9 (0.73) (0.80) 284.05 285.0 307.21 530.5 (0.69) (1.05)	46 Pd 3d5 Pd° PdO 335.1 337.0 (0.86) (0.97) 284.5 285.0 335.10 530.7 (0.77) (1.35)	47 Ag 3d5 Ag° Ag2O 368.2 367.5 (0.64) (1.00) 284.7 285.0 368.28 529.4 (0.62) (0.97)	48 Cd 3d5 Cd° CdO 405.0 404.0 (0.90) (1.38) 285.0 285.0 405.04 528.6 (0.61) (1.28)	49 In 3d5 In° In2O3 443.8 444.3 (1.08) (1.26) 284.9 285.0 443.87 529.9 (0.71) (1.19)	50 Sn 3d5 Sn° SnO2 484.9 487.3 (0.81) (1.28) 284.7 285.0 485.01 531.1 (0.68) (1.29)	51 Sb 3d5 Sb° Sb2O5 528.2 529.8 (1.0) (1.10) 284.6 285.0 528.26 531.3 (0.80) (0.86)	52 Te 3d5 Te° TeO2 572.8 576.5 (1.12) (1.27) 284.2 285.0 572.97 530.7 (0.83) (1.39)	53 I 3d5 KI 619.2 (1.30) 285.0 293.2 (1.11)	54 Xe 3d5 Xe+/Be Xe+/C 669.6 (1.13) 285.0
55 Cs 3d5 Cs° CsCl 724.6 (2.08) 285.0 199.2	56 Ba 3d5 Ba° BaOAc 780.0 (1.80) 285.0 531.4 (1.83)	57 La 3d5 La° La2O3 834.7 (3.0) 285.0 529.2 (1.6)	72 Hf 4f7 Hf° HfO2 14.4 17.1 (0.63) (1.26) 285.7 285.0 14.32 530.5 (0.62) (1.68)	73 Ta 4f7 Ta° Ta2O5 21.8 26.8 (0.80) (1.12) 285.0 285.0 21.78 531.0 (0.56) (1.46)	74 W 4f7 W° WO3 31.4 35.8 (0.58) (1.01) 285.3 285.0 31.38 530.6 (0.53) (1.27)	75 Re 4f7 Re° Re2O7 40.3 46.8 (0.67) (1.64) 285.3 285.0 40.30 532.1 (0.54) (1.58)	76 Os 4f7 Os° OsO4	77 Ir 4f7 Ir° IrO2 60.8 62.0 (0.80) (0.98) 284.4 285.0 60.88 530.2 (0.82) (0.97)	78 Pt 4f7 Pt° PtO2 71.0 75.1 (0.96) (1.16) 284.3 285.0 71.15 531.3 (0.88) (1.74)	79 Au 4f7 Au° Au2O3 84.1 88.1 (0.83) (1.12) 284.1 285.0 83.98 531.6 (0.68) (1.13)	80 Hg 4f7 Hg° HgO 99.8 100.7 --- (1.06) 285.0 (285.0) 99.81 532.9 (0.65) (0.96)	81 Tl 4f7 Tl° Tl2O3 117.8 117.4 (0.97) (1.01) 285.1 285.0 117.77 528.9 (0.66) (1.10)	82 Pb 4f7 Pb° PbO 136.9 137.5 (0.67) (1.10) 284.9 285.0 136.95 528.9 (0.63) (1.07)	83 Bi 4f7 Bi° Bi2O3 157.0 158.8 (0.73) (1.11) 284.6 285.0 157.05 529.6 (0.62) (1.58)	84 Po 4f7 Radioactive	85 At 4f7 Radioactive	86 Rn 4f7 Radioactive
87 Fr 4f7 Radioactive	88 Ra 4f7 Radioactive	89 Ac 4f7 Radioactive																

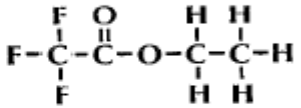
XPS International LLC: www.xpsdata.com

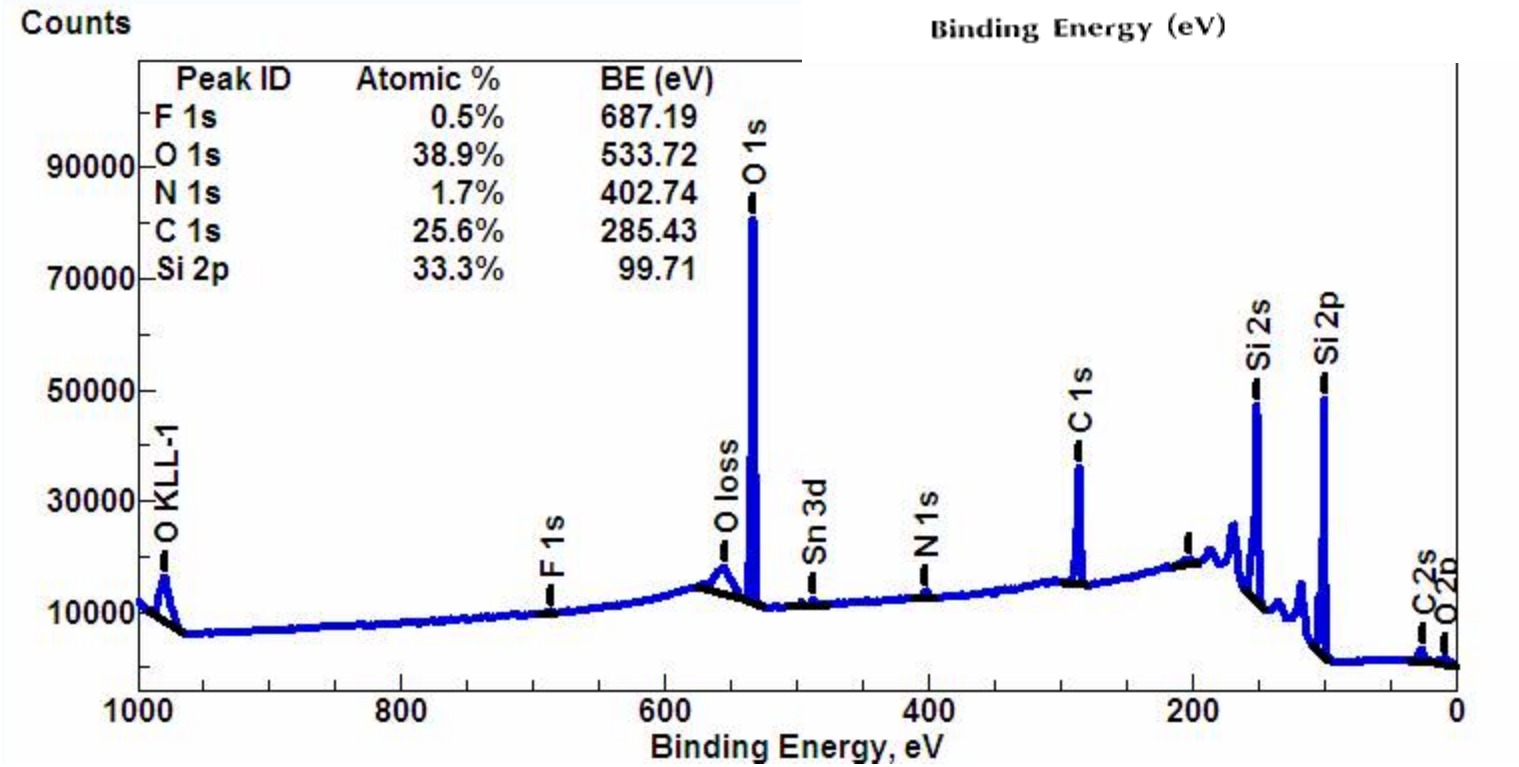
B. Vincent Crist
Last Update 4-28-97

58 Ce 3d5 Ce° CeO2	59 Pr 3d5 Pr° Pr2O5	60 Nd 3d5 Nd° Nd2O3	61 Pm 4d5 Pm° Pm2O3	62 Sm 4d5 Sm° Sm2O3	63 Eu 4d5 Eu° Eu2O3	64 Gd 4d5 Gd° Gd2O3	65 Tb 4d5 Tb° Tb3O7	66 Dy 4d5 Dy° Dy2O3	67 Ho 4d5 Ho° Ho2O3	68 Er 4d5 Er° Er2O3	69 Tm 4d5 Tm° Tm2O3	70 Yb 4f7 Yb° Yb2O3	71 Lu 4f7 Lu° Lu2O3
882.1 (2.0) 285.0 529.6 (2.00)	(931.98) 933.1 --- (4.4) --- 285.0 111.2 528.2 (2.17) (1.4)	(980.86) --- --- 118.0 (1.80)	Radioactive	--- (134.9) --- (10) --- 285.0 123.2 531.7 (2.57) (2.4)	128.2 135.6 --- (3.7) 284.3 285.0 128.18 529.2 (1.08) (1.4)	140.2 (1186.8) --- (5.4) 281.4 285.0 140.33 529.0 (1.02) (1.7)	145.9 (149.9) --- (7) --- 285.0 146.02 529.5 (1.33) (1.6)	152.4 (156.1) --- (7) --- 285.0 152.30 529.6 (1.88) (1.7)	159.8 161.3 --- ((6.0) --- 285.0 159.58 529.3 (1.50) (1.7)	167.7 168.5 --- (3.8) --- 285.0 167.25 529.2 (1.93) (1.9)	175.3 176.3 --- (3.4) 285.3 285.0 175.37 529.6 (1.92) (1.7)	1.07 184.9 --- (3.4) 285.6 285.0 (182.39) 529.4 (0.61) (2.0)	7.10 8.4 --- (3.0) 284.6 285.0 7.1 529.6 (0.69) (1.8)
90 Th 4f7 Th° ThO2	91 Pa 4f7	92 U 4f7 U° U2O3	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr
	Radioactive		Radioactive	Radioactive	Radioactive	Radioactive	Radioactive	Radioactive	Radioactive	Radioactive	Radioactive	Radioactive	Radioactive


MNN
MMM
KLL
Atomic Number
Electron Energy (KeV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90


C=O
C-O
C-C, C-H
C-F
295
285
Binding Energy (eV)




Counts
Peak ID Atomic % BE (eV)
F 1s 0.5% 687.19
O 1s 38.9% 533.72
N 1s 1.7% 402.74
C 1s 25.6% 285.43
Si 2p 33.3% 99.71
90000
70000
50000
30000
10000
O KLL-1
F 1s
O loss
O 1s
Sn 3d
N 1s
C 1s
Si 2s
Si 2p
C 2s
O 2s
1000
800
600
400
200
0
Binding Energy, eV