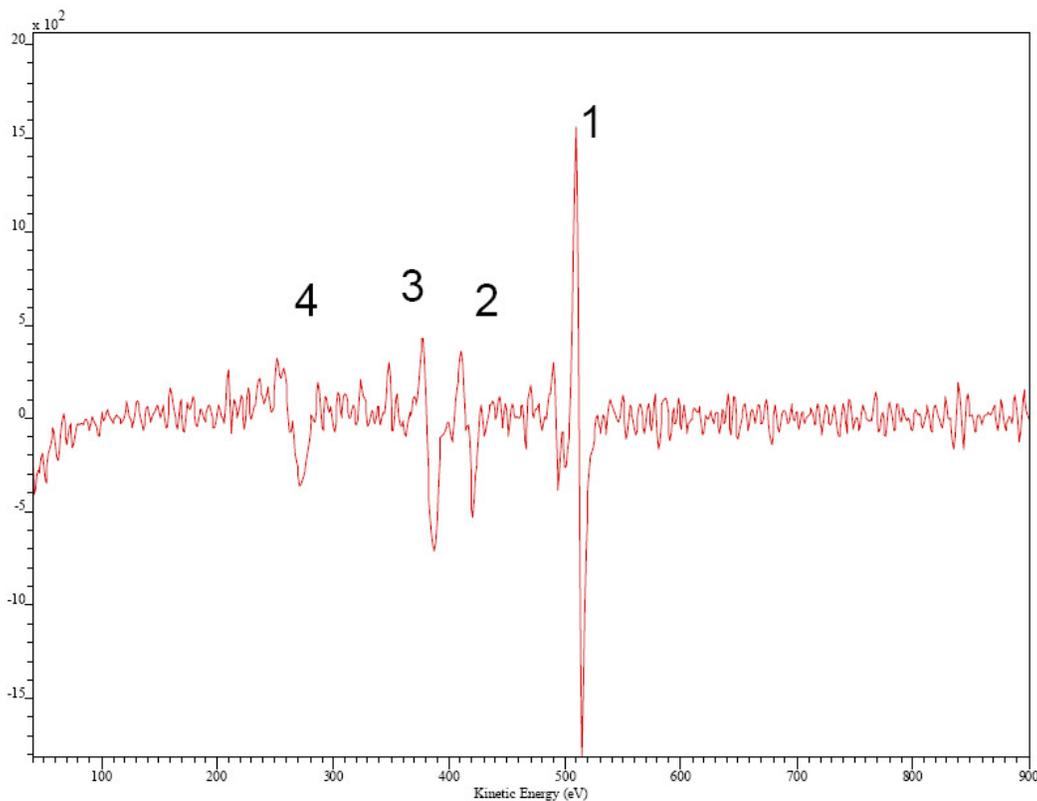


Name \_\_\_\_\_, ID \_\_\_\_\_

**NOTE:** Read the problem carefully and explain with detail the procedure followed. Please DO NOT write your answers on these papers. 10 points removed if units are lacking

1. Given the AES survey in Fig. 1, indicate the surface composition (i.e, the concentrations) using a method discussed in class.



**Figure 1.** AES survey of sample of interest. Numbers 1 to 4 refer to the peaks that are of interest in elemental identification.

Below you will find a three tables (table 1-3) with Auger electron peaks. Use it to find a solution to this problem. The columns indicate the energy, element and sensitivity, respectively. An additional table is included (table 4)

# Auger Handbook

Peak Energies 19 to 144 eV

Handbook of Auger Electron Spectroscopy

Appendix B. Auger Electron Peaks

Energy	Symbol	S <sub>i</sub>															
19	Gd	0.760	41	Eu	0.010	58	Ir	1.209	77	Rh	0.047	97	Hf	0.012	124	Nd	0.194
20	Tb	0.521	43	Th	0.238	58	Ba	0.282	77	Tb	0.007	99	Co	0.038	124	Mo	0.144
21	Dy	0.531	43	W	0.200	58	Re	0.045	78	Rb	0.107	99	La	0.128	124	Dy	0.112
22	Yb	0.609	43	Ag	0.104	58	Lu	0.011	78	Re	0.007	99	Au	0.015	124	Sm	0.095
22	Ho	0.567	43	Mo	0.075	58	U	0.011	79	Zn	0.069	99	Dy	0.014	124	Tl	0.022
24	Ca	0.983	43	Br	0.043	59	Ga	0.186	79	Si	0.042	100	Mo	0.026	125	Nb	0.074
24	Tm	0.587	43	Sc	0.034	59	Rb	0.060	79	Te	0.010	100	Th	0.015	125	Te	0.012
24	Er	0.533	43	As	0.030	60	Th	0.067	80	Sb	0.012	101	U	0.256	125	Yb	0.011
25	U	0.444	44	Ir	0.697	61	Au	0.114	80	Mn	0.011	102	Br	0.151	126	Eu	0.084
26	Lu	0.613	44	Rh	0.626	61	Sm	0.006	81	Hg	1.070	103	Sm	0.385	126	Gd	0.045
27	Sc	1.007	44	Al	0.022	61	I	0.077	81	Ag	0.045	104	Ce	0.174	129	Mo	0.141
28	Sb	0.360	45	Mn	0.843	62	Mg	0.025	81	Ge	0.009	104	Se	0.120	129	Zr	0.130
29	Nb	1.373	45	Tl	0.162	62	Se	0.006	82	Sm	0.058	105	Si	0.790	130	Ho	0.118
29	Hf	0.868	46	Hf	0.021	63	Tl	0.096	82	Pd	0.029	105	Ho	0.016	130	Zn	0.022
29	Pr	0.017	47	Pd	0.368	63	Pb	0.066	82	Cd	0.024	105	W	0.006	130	Nd	0.005
30	Tl	1.228	47	Se	0.302	63	Bi	0.077	82	Sn	0.018	106	Y	0.112	131	Hf	0.023
30	Na	0.528	47	Re	0.259	63	In	0.070	82	In	0.015	106	Ni	0.060	131	Tb	0.023
30	Nd	0.019	48	Pt	0.726	63	Hf	0.008	83	La	0.626	106	Tl	0.030	132	Y	0.281
31	Ta	0.822	48	Mg	0.649	63	V	0.004	83	Y	0.133	106	Kr	*	132	Zr	0.126
31	Os	0.205	48	Au	0.464	64	Ni	0.773	84	Th	0.186	107	Eu	0.405	132	Bi	0.077
31	Ag	0.199	48	Os	0.407	64	Zn	0.680	84	Ga	0.057	107	Rb	0.041	132	Ta	0.019
32	Mo	1.267	48	As	0.055	64	La	0.229	85	Os	0.011	108	Be	0.403	132	W	0.015
32	Rh	0.277	48	Cu	0.029	64	Te	0.067	85	As	0.010	108	As	0.011	133	Gd	0.113
32	La	0.022	49	Ce	0.235	64	Eu	0.009	86	Eu	0.057	109	Nb	0.205	133	Cs	0.007
32	Sm	0.009	49	Cd	0.132	65	Cs	0.073	86	Al	0.017	109	Br	0.121	134	Pb	0.031
33	Pt	0.640	49	Ta	0.078	66	Cu	0.735	87	Ce	0.730	110	P	0.113	134	Tl	0.023
33	Pd	0.237	49	Si	0.017	66	Sb	0.110	87	Nb	0.028	110	Cu	0.083	135	Sm	0.175
34	Ce	0.034	49	Fe	1.181	66	Sn	0.099	87	Cs	0.007	110	Pb	0.015	135	Hg	0.026
34	Se	0.031	50	Li	0.232	66	U	0.072	87	Mg	0.003	111	Gd	0.321	135	Re	0.017
34	Ca	0.005	50	Ag	0.188	66	Ta	0.011	88	Se	0.020	111	Pr	0.170	135	Ir	0.012
34	Lu	0.003	50	U	0.132	67	Kr	*	89	Fe	0.031	111	Ga	0.052	135	Sr	0.008
35	V	0.872	50	Ti	0.070	68	Ce	0.160	89	Bi	0.017	112	Zn	0.110	136	Nb	0.191
35	W	0.692	50	Ru	0.020	69	Th	1.066	90	Tl	1.238	112	U	0.088	136	Ru	0.031
35	Pr	0.017	51	Th	0.172	70	Pt	1.103	90	Br	0.028	112	Ge	0.030	137	Er	0.076
36	As	0.259	51	Ge	0.084	70	Al	0.655	90	Hg	0.018	112	Si	0.013	137	Dy	0.026
36	Te	0.221	51	Rb	0.027	70	Sr	0.100	91	Pr	0.616	114	Sr	0.108	137	Cs	0.016
36	Br	0.036	51	Dy	0.004	71	Pd	0.028	91	Sr	0.094	115	Nd	0.208	138	Tb	0.029
37	Re	1.993	52	Zn	0.061	71	Cr	0.018	91	Gd	0.031	115	Rb	0.029	139	Ag	0.011
37	Ge	0.022	52	Yb	0.012	71	Ru	0.007	91	Ba	0.030	116	Tb	0.149	139	P	0.015
37	Yb	0.014	53	W	0.110	72	W	0.004	92	Ge	0.057	117	Y	0.048	140	Eu	0.235
38	I	0.608	53	V	0.061	72	Pr	0.108	92	Th	0.033	117	Tm	0.011	140	Ga	0.027
38	Mg	0.128	54	Tm	0.011	72	Dy	0.006	92	Ir	0.010	117	Re	0.004	141	Rh	0.032
38	Hf	0.060	54	Er	0.015	73	U	0.096	93	U	0.890	118	Sb	0.008	141	Th	0.013
39	Cr	1.336	55	Br	0.274	73	Y	0.026	95	Tb	0.016	118	W	0.003	142	Gd	0.368
39	Li	0.580	55	Ge	0.148	73	Cd	0.011	96	Si	0.924	119	Pb	0.084	142	Pd	0.016
39	Zn	0.072	55	Cr	0.063	74	Au	1.420	96	Nd	0.618	121	Zr	0.272	142	Ge	0.013
40	Ru	0.698	55	Al	0.030	74	I	0.078	96	Zr	0.262	121	Ce	0.068	143	Mo	0.043
40	Os	0.658	55	Nd	0.004	76	Ba	0.242	97	Pb	1.160	121	Bi	0.028	143	Re	0.018
40	Ta	0.150	57	Co	0.807	76	Nd	0.106	97	As	0.064	121	Hf	0.010	143	Si	0.002
40	U	0.081	57	Li	0.089	76	Zr	0.033	97	Rb	0.020	122	Pr	0.166	144	Tm	0.054
41	Na	0.024				77	U	1.684	97	Pt	0.016	123	P	1.382	144	Hg	0.025

\* Sensitivity factors were not calculated for the inert gases.

**Table 1.** The table includes the energies, symbols and sensitivity, in the respective columns.

Energy	Symbol	S <sub>i</sub>															
144	Y	0.017	165	Re	0.184	187	Ti	0.009	228	Sr	0.005	269	U	0.087	306	Nd	0.005
145	Ho	0.051	165	Hf	0.030	188	Ru	0.043	230	Re	0.050	269	Pb	0.054	308	Ir	0.007
145	Ti	0.034	165	Ag	0.007	188	Au	0.021	231	Sn	0.011	271	La	0.002	312	Yb	0.015
145	W	0.020	165	Pd	0.007	189	Y	0.002	232	Th	0.146	272	Bi	0.041	312	Pt	0.006
145	Sr	0.002	165	Tl	0.004	190	Mo	0.633	232	Eu	0.021	275	C	0.281	312	W	0.006
146	Nb	0.195	165	Ba	0.004	190	U	0.115	233	Ir	0.104	275	Th	0.012	313	Tm	0.006
146	Au	0.072	166	Ir	0.144	190	Pt	0.021	235	Ru	0.424	275	Tb	0.004	313	Nb	0.004
146	Ba	0.009	167	Pr	0.001	192	Pd	0.044	235	Sb	0.010	275	Os	0.002	314	Sc	0.060
147	Dy	0.071	168	W	0.186	193	La	0.002	236	Sr	0.002	275	Zr	0.013	314	Zr	0.009
148	Yb	0.017	168	Er	0.161	193	Os	0.009	238	Bi	0.007	276	K	0.066	315	Ti	0.002
148	As	0.014	168	Au	0.074	194	S	0.023	239	Os	0.035	276	Ho	0.018	317	Th	0.021
150	Tb	0.169	168	Ce	0.003	194	Ag	0.027	239	La	0.002	276	Y	0.010	317	U	0.006
150	Ta	0.007	168	Sb	0.003	195	Pr	0.021	241	Pt	0.096	276	Lu	0.003	319	Sn	0.084
151	Zr	0.758	169	Os	0.155	196	Cd	0.024	241	Gd	0.026	276	Dy	0.003	320	Re	0.004
151	Ge	0.004	169	Se	0.006	196	Te	0.012	242	Mo	0.014	276	Nd	0.002	320	Ba	0.002
152	Mo	0.104	170	Nb	0.707	197	Hf	0.024	242	U	0.008	277	Ru	1.126	322	Ca	0.229
152	Er	0.078	170	Ta	0.257	197	Sb	0.014	243	Au	0.122	279	Th	0.012	322	Sc	0.074
152	Hf	0.032	170	Tm	0.212	198	Ir	0.024	245	C	0.019	281	Cd	0.107	323	Rh	0.006
152	Lu	0.016	171	Re	0.233	198	Sn	0.014	245	Sm	0.005	282	Ce	0.002	323	Lu	0.021
152	Ni	0.007	172	Cl	0.707	198	In	0.013	246	Hg	0.084	283	Pd	0.352	323	Mo	0.007
153	S	2.430	172	Hf	0.164	201	Nb	0.372	247	Pd	0.182	284	U	0.493	323	Ta	0.004
154	Dy	0.161	172	Rh	0.044	203	Ta	0.059	247	Ir	0.059	287	Cd	0.087	324	Cd	0.194
154	Au	0.092	173	W	0.327	204	Nd	0.031	249	Th	0.182	287	Y	0.004	325	Au	0.011
155	Ru	0.087	173	Pt	0.103	204	Au	0.018	250	Tl	0.074	287	Dy	0.002	325	Sm	0.006
155	Pt	0.083	174	Yb	0.194	204	Pt	0.015	250	Sr	0.003	288	Er	0.016	325	Hf	0.005
155	Hg	0.044	175	Ta	0.295	204	Ce	0.002	251	Pb	0.082	288	Ho	0.002	326	Sn	0.058
155	Yb	0.018	175	Lu	0.173	205	Ru	0.213	251	Ce	0.002	290	Lu	0.002	326	Th	0.006
156	Th	0.066	175	Ir	0.167	205	Ar	*	252	K	0.715	291	Th	0.003	327	Os	0.005
156	Y	0.032	176	Hf	0.231	205	Dy	0.002	252	Tb	0.015	293	Re	0.015	328	Yb	0.016
156	U	0.008	177	La	0.011	206	Ti	0.008	252	Y	0.008	294	U	0.104	330	Nb	0.019
157	Ho	0.144	178	Zr	0.190	206	Pb	0.007	253	Bi	0.063	294	Be	0.002	330	Xe	*
157	Tm	0.118	179	Re	0.297	207	Rh	0.044	253	Rb	0.004	295	Ru	0.011	333	Pd	2.038
157	Hf	0.037	179	Pr	0.003	207	Hf	0.015	254	Rb	0.004	296	Nd	0.003	333	Tl	0.023
157	Se	0.014	180	Yb	0.184	207	Th	0.009	256	Pt	0.056	296	Mo	0.001	333	Ir	0.005
157	Zn	0.006	180	Os	0.172	208	Rb	0.006	256	La	0.002	297	Ca	0.492	334	Hf	0.022
158	Ir	0.102	180	Yb	0.151	209	Bi	0.004	257	Th	0.011	297	Tl	0.003	334	U	0.013
158	As	0.006	180	Ru	0.025	210	W	0.072	257	Eu	0.007	297	Ho	0.002	335	Lu	0.013
159	La	0.006	180	Sr	0.002	215	Pr	0.006	259	Rh	0.522	299	Nb	0.009	336	Mo	0.002
159	Ce	0.002	181	Ba	0.004	218	Re	0.109	259	Au	0.066	299	Pr	0.002	337	Sb	0.123
160	Ta	0.037	182	W	0.340	218	Ta	0.038	259	U	0.046	300	In	0.068	337	Bi	0.003
161	Lu	0.042	182	Lu	0.192	219	Ar	*	259	Ca	0.020	300	Sc	0.021	337	La	0.001
162	Ho	0.170	183	Ta	0.373	221	K	0.067	260	Sr	0.001	300	Tm	0.020	339	Te	0.008
162	Th	0.129	183	U	0.056	221	W	0.053	261	Pr	0.002	300	Th	0.006	341	Hf	0.023
162	Os	0.095	183	Bi	0.004	223	Sm	0.025	262	Ag	0.116	300	Hf	0.003	342	Au	0.012
163	Cl	0.329	184	S	0.019	223	Cd	0.014	262	Hg	0.044	301	Er	0.004	342	Th	0.008
163	Pt	0.102	184	Cl	6.420	223	Nd	0.006	262	Y	0.003	302	Zr	0.019	343	Sc	0.625
163	Zr	0.028	184	Hf	0.268	224	Th	0.078	263	Gd	0.010	303	Ag	0.255	343	Tb	0.003
164	Au	0.084	184	Pb	0.010	225	Mo	0.553	264	Dy	0.014	304	Sn	0.009	344	Ta	0.059
164	Yb	0.036	185	B	0.391	225	Rh	0.272	264	Ba	0.001	305	Rh	1.974	344	Nb	0.008
164	Pb	0.006	185	Nd	0.003	226	Os	0.075	266	Tl	0.049	306	In	0.047	344	Gd	0.006
165	Mo	0.249	186	Ce	0.018	228	In	0.006	267	Ag	0.121	306	Ta	0.005	345	Pb	0.006

\* Sensitivity factors were not calculated for the inert gases.

Table 2. . The table includes the energies, symbols and sensitivity, in the respective columns.

Peak Energies 345 to 643 eV

Handbook of Auger Electron Spectroscopy  
Appendix B. Auger Electron Peaks

Energy	Symbol	S <sub>i</sub>															
345	Sb	0.077	379	Cd	2.610	421	Bi	0.009	468	Sn	0.060	512	Ir	0.005	571	Pt	0.005
345	U	0.012	381	I	0.033	421	Lu	0.004	468	Xe	*	513	Ta	0.013	572	Cr	0.389
346	In	0.118	382	Sb	0.057	422	Sm	0.003	469	Mn	0.012	515	Ba	0.068	572	Ce	0.247
347	Ca	0.007	384	Ir	0.025	425	Te	0.027	469	Pt	0.006	515	Pb	0.005	572	Co	0.008
349	Pd	0.005	385	Cd	2.430	425	Hf	0.008	471	Rh	0.008	515	Ho	0.004	573	Ce	0.019
349	Ti	0.004	385	Tl	0.319	426	Re	0.019	471	Ta	0.004	515	Xe	*	575	Th	0.002
351	Lu	0.002	386	Hf	0.010	427	V	0.051	472	Yb	0.004	516	U	0.003	581	Au	0.006
352	Re	0.028	387	Ca	0.005	427	In	0.045	473	O	0.071	517	Os	0.003	582	Cr	0.024
353	Ag	2.265	388	U	0.046	428	Ba	0.023	474	Tl	0.003	518	Rh	0.005	583	U	0.005
353	W	0.055	388	Er	0.008	428	Ta	0.010	475	V	1.013	518	Tl	0.002	584	Ti	0.005
353	Tb	0.004	388	Lu	0.005	428	Pd	0.004	475	Re	0.003	519	I	0.955	589	F	0.038
354	Th	0.008	389	N	0.600	430	Er	0.003	475	Tb	0.003	519	Bi	0.004	589	Ag	0.002
354	Yb	0.004	389	Bi	0.011	431	Ir	0.011	476	Ce	0.031	519	Fe	0.012	591	Yb	0.003
355	Os	0.016	389	Nd	0.003	432	Sn	1.732	478	Cd	0.003	519	Te	0.031	591	Th	0.002
356	Te	0.088	390	Ti	0.702	432	W	0.013	479	Pd	0.011	524	W	0.012	592	Mn	0.599
356	La	0.001	390	Xe	*	433	V	0.192	479	Ce	0.010	528	La	0.032	592	Ba	0.261
357	Ti	0.085	391	W	0.012	434	In	0.030	482	Au	0.007	530	Pd	0.002	593	Fe	0.127
357	Au	0.013	391	Mo	0.001	436	I	0.125	483	Pb	0.003	530	Te	0.104	593	Pr	0.022
357	Tl	0.012	392	Sb	0.081	437	Os	0.014	484	Cr	0.124	531	Cr	0.987	593	Cd	0.004
358	N	0.047	392	Pb	0.009	438	Ru	0.006	485	Sb	0.037	531	Th	0.005	597	Sm	0.011
358	Ir	0.019	394	In	0.229	439	Sn	1.195	485	W	0.006	533	Ir	0.004	598	Sn	0.004
358	Mo	0.017	394	Cd	0.021	439	Ba	0.017	485	Lu	0.005	533	Ag	0.003	599	Pb	0.007
359	Ag	2.361	395	Pt	0.018	439	Au	0.006	486	Te	1.255	534	La	0.026	599	Xe	*
360	Sn	0.063	397	Ta	0.006	440	V	0.658	488	Cs	0.022	536	Re	0.008	600	In	0.002
361	U	0.049	398	Sc	0.042	440	Ir	0.015	489	O	0.204	537	Cs	0.020	600	Fe	0.383
361	Pt	0.017	399	Hf	0.007	442	Sb	0.170	490	Ce	0.012	537	Nd	0.015	603	Ba	0.264
361	Dy	0.005	400	Cd	0.031	443	Th	0.003	491	Cr	0.843	537	Cd	0.008	604	Th	0.001
363	Re	0.043	400	Au	0.017	443	Eu	0.004	493	Bi	0.004	537	Xe	*	608	Co	0.037
365	Te	0.038	402	V	0.086	445	I	0.085	493	Rh	0.004	538	Mn	0.106	608	Lu	0.003
365	Xe	*	402	Tm	0.007	449	Rh	0.016	494	Te	1.035	539	Te	0.050	610	Xe	*
366	Tl	0.131	403	Sn	0.032	449	Pt	0.011	494	Sb	0.121	540	Er	0.004	613	F	0.243
366	Rh	0.004	404	Re	0.010	449	Tm	0.003	494	Dy	0.003	541	La	0.030	613	Fe	0.063
366	Hf	0.004	404	Rh	0.005	449	Ag	0.003	495	Os	0.003	545	Mn	0.456	613	Bi	0.005
368	Lu	0.005	405	In	1.609	450	Cr	0.096	497	Re	0.003	546	Pt	0.004	620	Co	0.089
369	Th	0.003	405	Cs	0.018	450	La	0.012	498	Cr	0.036	547	Xe	*	623	La	0.189
370	Sc	0.654	407	Ta	0.014	453	Ti	0.147	500	I	0.078	548	Os	0.006	625	Cr	0.002
370	Cd	0.167	409	Mo	0.001	455	Au	0.011	500	Mn	0.052	549	U	0.009	626	Nd	0.028
370	Sn	0.122	410	Bi	0.009	456	Gd	0.005	500	Hf	0.007	553	Fe	0.046	626	Ni	0.007
371	I	0.073	411	Tl	0.007	456	Hf	0.004	500	Th	0.006	554	Mn	0.053	626	Cd	0.002
372	Pb	0.013	412	In	1.074	458	Sb	1.954	503	Sb	0.090	557	Ag	0.002	627	Eu	0.010
373	N	0.151	413	V	0.149	458	Xe	*	503	Ba	0.047	558	Ir	0.006	627	Hf	0.005
373	Mo	0.008	413	Yb	0.006	460	Sn	0.085	503	Tl	0.003	558	Au	0.004	627	In	0.002
374	Os	0.020	416	Pb	0.009	460	Tl	0.003	504	Pd	0.008	559	Cs	0.241	630	Sb	0.007
374	Pr	0.001	416	Te	0.077	460	Ru	0.002	504	In	0.002	560	Ce	0.024	631	Sn	0.003
375	Ho	0.008	416	Cs	0.017	461	Cr	0.162	507	Pr	0.011	561	Tm	0.004	632	F	0.733
375	Tl	0.006	417	W	0.014	461	La	0.016	507	Ag	0.010	562	I	0.139	632	Ce	0.034
375	Ru	0.004	418	Sn	0.191	463	Pb	0.004	510	I	1.069	564	Cd	0.005	633	Eu	0.010
377	U	0.024	418	Ru	0.014	463	Bi	0.004	510	O	0.788	565	Fe	0.120	634	La	0.220
377	V	0.021	419	Os	0.005	466	Sb	1.488	511	V	0.242	566	Ce	0.018	638	Mn	0.458
378	Ta	0.006	421	Tl	1.103	466	Be	0.012	512	Mn	0.143	567	In	0.005	640	F	0.106
378	Yb	0.004	421	Cr	0.021	468	Te	0.089	512	Sn	0.006	571	I	0.101	643	U	0.009

\* Sensitivity factors were not calculated for the inert gases.

Table 3. . The table includes the energies, symbols and sensitivity, in the respective columns.

Table 5. Derivative of Auger electron energies of the elements.

# $\frac{d}{dE} \{E \cdot N(E)\}$ Auger Electron Energies of the Elements

H	1
Li	Be
3	4
• 28	
• 40	
• 47 • 104	
• 52	

$\frac{d}{dE} \{E \cdot N(E)\}$

E

He	2				
B	C	N	O	F	Ne
5	6	7	8	9	10
	• 357	• 475	• 605	• 790	
	• 20	• 367	• 490	• 625	• 800
• 180	• 272	• 381	• 510	• 650	• 822
		• 389			

Na	Mg
11	12
	• 34
	• 45
	• 58
• 923	• 1106
• 951	• 1140
• 963	• 1175
• 990	• 1186

Al	Si	P	S	Cl	Ar
13	14	15	16	17	18
	• 68	• 92	• 120	• 152	• 181
	• 84	• 107			• 215
• 1345	• 1561	• 1800			
• 1364	• 1583	• 1819			
• 1380	• 1601	• 1850	• 2049		
• 1396	• 1619	• 1865	• 2121	• 2381	

K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
	• 20	• 24	• 27	• 31	• 36	• 41	• 47	• 53	• 61	• 60	• 59	• 55	• 23	• 31	• 43	• 55	
							• 86	• 95	• 102	• 105	• 107		• 52		• 99	• 102	
• 221	• 255	• 319	• 383	• 431	• 459	• 510	• 562	• 618	• 715	• 776	• 836	• 898	• 963	• 1030	• 1098	• 1172	
• 237	• 291	• 336	• 387	• 437	• 489	• 542	• 598	• 656	• 716	• 783	• 849	• 916	• 985	• 1056	• 1129	• 1205	• 1285
• 252	• 294	• 340	• 418	• 473	• 529	• 589	• 703	• 775	• 848	• 920	• 994	• 1070	• 1147	• 1228	• 1315	• 1396	
• 274	• 318	• 367	• 451	• 509	• 571	• 636				• 940	• 1017	• 1097	• 1178	• 1264	• 1353	• 1442	

Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
	• 15	• 18	• 21	• 24	• 28		• 37	• 40	• 43	• 49				• 26	• 31	• 37	
					• 38				• 78	• 80							
• 57	• 65	• 100	• 92	• 105	• 120		• 200	• 222	• 243	• 266	• 277	• 298	• 316				
• 76	• 76	• 110	• 115	• 132	• 161		• 231	• 256	• 279	• 301	• 321	• 344	• 367	• 388	• 413	• 437	• 519
• 106	• 103	• 127	• 147	• 167	• 186		• 273	• 302	• 326	• 351	• 376	• 404	• 430	• 454	• 483	• 511	• 536
• 114	• 110		• 174	• 197	• 221				• 330	• 356	• 382	• 410	• 437	• 462	• 491	• 520	• 544
• 1384	• 1380	• 1462	• 1547	• 1632	• 1719		• 2089	• 2168	• 2259								
• 1439	• 1517	• 1602	• 1695	• 1788	• 1890		• 2270	• 2355	• 2289								
• 1625	• 1717	• 1821	• 1928	• 2037	• 2150		• 2400										

Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
			• 23	• 26	• 38	• 33											
			• 167	• 35	• 163	• 161	• 66										
• 47	• 52	• 78	• 185	• 179	• 179	• 176	• 177	• 54	• 64	• 69	• 76	• 84	• 94	• 101			
	• 66	• 95					• 221	• 171	• 168	• 150	• 243	• 244	• 249	• 249			
							• 229	• 237	• 239		• 262	• 267	• 268				
• 479	• 500	• 532	• 1227	• 1270	• 1310	• 1354	• 1393	• 1437	• 1486	• 1523	• 1829	• 1865	• 1912	• 1965			
• 583	• 584	• 625	• 1624	• 1680	• 1736	• 1799	• 1846	• 1908	• 1967	• 2024	• 2079	• 2135	• 2187	• 2249			
• 575	• 600	• 713	• 1676	• 1737	• 1796	• 1858	• 1919	• 1981	• 2044	• 2111	• 2170	• 2230	• 2288	• 2356			
• 636	• 671	• 729															

Fr	Ra	Ac
87	88	89

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
58	59	60	61	62	63	64	65	66	67	68	69	70	71
					• 80	• 87	• 108	• 113	• 121	• 125	• 131	• 19	• 18
	• 64	• 67	• 72		• 100	• 109	• 138	• 146	• 151	• 157	• 163	• 166	• 170
• 82	• 87	• 91		• 118	• 126		• 118	• 126				• 169	• 178
• 116	• 119	• 126		• 133	• 139		• 133	• 139					• 171
• 563	• 596	• 628		• 698	• 734	• 767	• 798	• 976	• 1014	• 1052	• 1099	• 1141	• 1185
• 661	• 699	• 730		• 814	• 858	• 895	• 933	• 1126	• 1175	• 1225	• 1274	• 1325	• 1378
• 752	• 812	• 854		• 944	• 988	• 1029	• 1073	• 1284	• 1338	• 1393	• 1493	• 1560	• 1620
• 769	• 926	• 973		• 1076	• 1123	• 1176	• 1226	• 1351	• 1371	• 1430			

Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
90	91	92	93	94	95	96	97	98	99	100	101	102	103
• 72													
• 87													
• 288													
• 291													

Unit of energy: eV  
 Dots indicate the relative intensity of the peaks in each Auger transition.  
 • 1.0~0.8  
 • 0.8~0.3  
 • 0.3~0.1

Table 4. Derivative of Auger electron energies of the elements.

**SOLUTION.**

The energies of the peaks numbered are **(25 points; for proper identification of the energies)**:

1.  $E_k = 511 \text{ eV}$
2.  $E_k = 420 \text{ eV}$
3.  $E_k = 385 \text{ eV}$
4.  $E_k = 271 \text{ eV}$

To estimate the concentrations using the simplest method we can use the expression **(10 points; for indicating the expression used)**:

$$C_x = \frac{I_x / S_x}{\sum_i I_i / S_i}$$

where  $I_x$  = peak-to-peak intensity,  $S_x$  = sensitivity, and  $C_x$  = atomic concentration **(10 points; for identification of variables)**.

Using a ruler the peak intensities can be measured; other options could also be suitable: **(20 points; for correct numerical answer)**

Name	I[mm]	atomic percentage concentration
C KLL	17	23.25%
Ti LMM	28	
	22	36.26% (added contribution)
O KLL	508 eV	40.48%

$$C_C = \frac{17 / 0.281}{260.178} = 0.2325$$

$$C_{Ti} = \frac{28 / 1.103 + 22 / 0.319}{260.178} = 0.3626$$

$$C_O = \frac{83 / 0.788}{260.178} = 0.4048$$

The student should indicate clearly how each atomic percentage was calculated **(30 points; for procedure)**.

**5 points** if the answer is reasonably well organized.

2. Assume that copper film is grown on palladium substrate. It is observed that the substrate XPS peak (BE = 335 eV) yields a signal attenuated by 40% as the film grows. The radiation used is Al-K-alpha ( $h\nu = 1486.6$  eV). The work function of copper is  $\phi = 5$  eV.

Make an estimation of the **copper thickness film** by using the expressions indicated below.

For the inelastic mean free path (IMFP) we have the next empirical formula:

$$\lambda[nm] = \frac{538a}{E_k} + 0.41a^{3/2} E_k^{1/2},$$

where,  $a$  = mean atomic diameter [nm],  $E_k$  = kinetic energy of the electron [eV].

You will also need to recall Beer-Lambert law of attenuation:

$$I = I_0 e^{-d/\lambda}$$

Where  $I$  = attenuated intensity,  $I_0$  = original intensity,  $d$  = thickness and  $\lambda$  = IMFP.

In class we discussed how to calculate the mean atomic diameter, for which you will need to know the density of copper =  $8.93 \text{ g/cm}^3$ , the molar mass of copper =  $63.54 \text{ g/mol}$ .

### **SOLUTION.**

First we calculate the mean atomic diameter (**20 points**):

$$a = \left[ \frac{A}{1000\rho N_A} \right]^{1/3} = \left[ \frac{63.54 \text{ g/mol}}{1000(8.93 \times 10^3 \text{ kg/m}^3)(6.02 \times 10^{23} \text{ mol}^{-1})} \right]^{1/3} = 2.27 \times 10^{-10} \text{ m}$$

where  $\rho$  = density [ $\text{kg/m}^3$ ],  $A$  = molar mass [ $\text{g/mol}$ ], and  $N_A$  = Avogadro's number =  $6.02 \times 10^{23} \text{ mol}^{-1}$ .

The kinetic energy is **(20 points)**:

$$E_k = h\nu - E_{BE} - \phi = 1486.6eV - 335eV - 5eV = 1146.6eV$$

Substituting the two previous results in the expression for IMFP**(60 points)**:

$$\begin{aligned}\lambda[nm] &= \frac{538a}{E_k} + 0.41a^{3/2}E_k^{1/2} = \frac{538(0.227nm)}{1146.6eV} + 0.41(0.227nm)^{3/2}(1146.6eV)^{1/2} \\ &= 1.608nm\end{aligned}$$

From the Beer-Lambert equation after an algebraic manipulation **(10 points)**:

$$d = -\lambda \ln\left(\frac{I}{I_0}\right) = -(1.608nm)\ln(0.4) = 1.47nm$$

Thus the thickness of the film is 1.47nm