

Supplementary material for : Limits of detection in elemental analysis of food via laser-induced breakdown spectroscopy

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1. Apparatus response function

The apparatus response function was measured using a deuterium arc (Optronic Laboratories, model OL UV-40) and a tungsten filament lamp (Optronic Laboratories, model OL 220M) for the ultraviolet and visible/near infrared spectral ranges, respectively. Both the spectral and the intensity calibration were checked regularly using a procedure based on the simulation of the LIBS spectrum of steel [1].

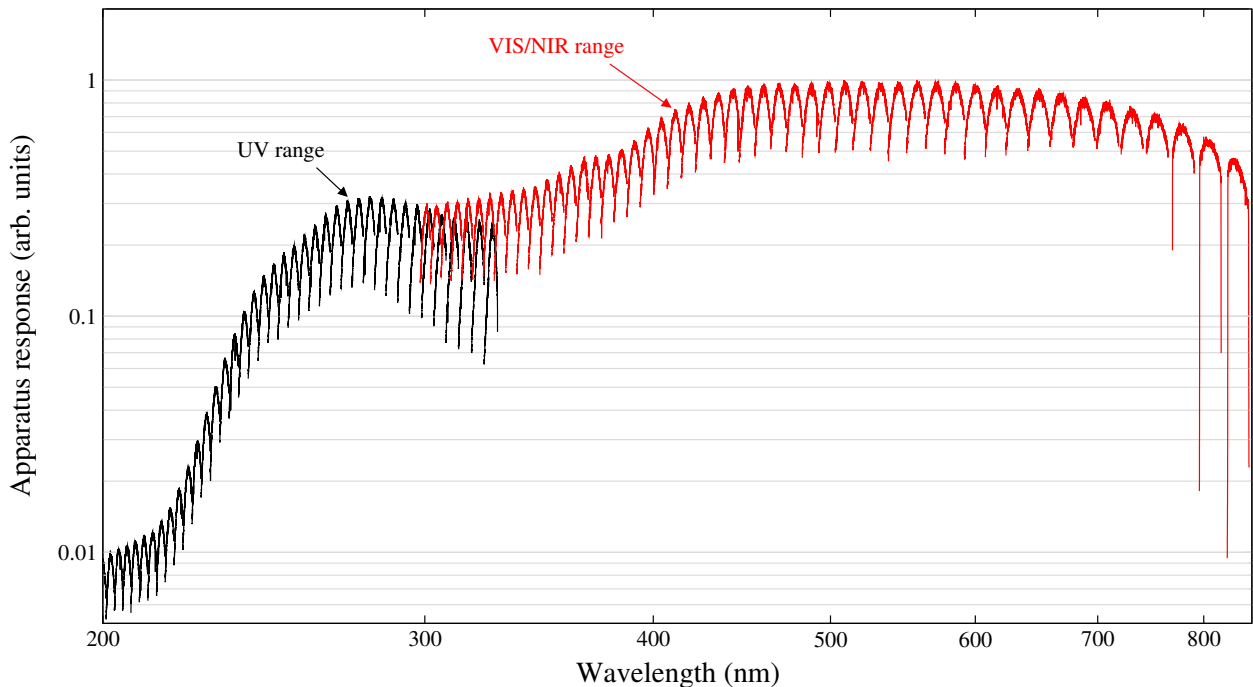


Figure 1: Apparatus response function for the ultraviolet and visible/near infrared spectral ranges of the used echelle spectrometer (Lasertechnik Berlin, model Aryelle Butterfly).

2. Analysis of background signal

The measured spectrum (black) and the spectrum obtained after smoothing (red) are displayed in Fig. 1(a) for the spectral range of the As I 234.98 nm transition. The noise function that characterizes the data point fluctuation associated to the background signal is obtained by subtracting the smoothen spectrum from the original measured one [see Fig. 1(b)]. The displayed spectral range includes 345 data points that were found to present a sufficiently large data size for reliable statistical analysis, enabling thus the accurate determination of the sample standard deviation of the background signal.

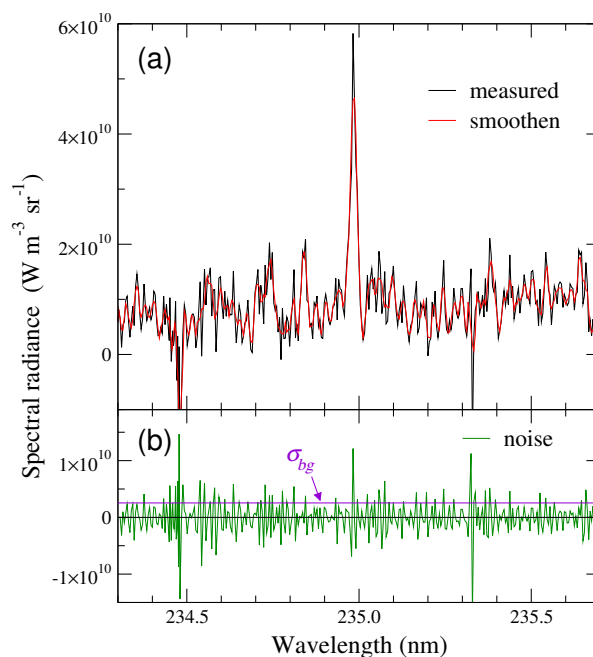


Figure 2: (a) Measured spectrum before and after smoothing with an appropriate procedure. (b) Noise function obtained by subtracting the smoothen spectrum from the original measured one. The standard deviation of the noise σ_{bg} is indicated by the purple colored line.

3. Analytical transitions with corresponding LOD

The analytical transitions were chosen according to the signal-to-noise ratio and the interferences with transitions emitted by atomic or molecular species that originate from the organic matrix or from the most abundant minerals. The most sensitive transitions are presented in Table 1 for each element together with alternative transitions of equal or close sensitivity that may be used for analytical measurements in case of interferences with transitions from other minor or trace elements listed in the last column.

Most of the transitions have been previously observed in calibration-free LIBS analyses of various materials [2, 3, 4, 5, 6, 7]. For these lines, the Stark broadening parameters are given in Table 5. The limits of detection of the corresponding elements can thus be considered as validated. Moreover, a high level of confidence can be attributed to all LOD-values obtained with transitions for which reliable spectroscopic data are available in the NIST database.

The previous validation of the here applied sensitivity-improved calibration-free approach showed that trace element concentrations can be quantified with an uncertainty better than 50% for most elements. This value of confidence can be safely applied to the C_{LOD} -values of all elements that have been previously quantified in food or other sample materials, indicated by the filled and empty red circles in Fig. 7, respectively. For the other elements, the expected uncertainty ΔC_{LOD} is the same if the spectroscopic data required for the spectral line intensity calculation are reliable. For some elements, and in particular those of largest atomic number, the uncertainty of the Einstein coefficients of spontaneous emission is not reported (see Table 5) and the uncertainty of the corresponding C_{LOD} -value is therefore unknown.

Table 1: Limit of detection C_{LOD} in mass fraction units, analytical transition, apparatus response R_{app} , possibly interfering lines, and material for which the analytical transition was measured. All C_{LOD} -values are given with a single significant digit according to the estimated uncertainty of 50%. If available, C_{LOD} -values are given for alternative transitions with similar analytical performance. The spectroscopic data of the transitions are given in Table 5.

Element	C_{LOD} (ppm)	Transition	R_{app}	possibly interfering transitions	validation
Ac	Actinium	Ac II 315.308	0.23		-
		Ac II 299.416	0.14		-
Ag	Silver	Ag I 328.068	0.20		alloy
		Ag I 338.288	0.26		alloy
Al	Aluminum	Al I 396.152	0.57		food
		Al I 394.400	0.40	Ce II 394.388, U II 394.413	food
		Al I 308.215	0.09	Gd II 308.199	food
As	Arsenic	As I 234.984	0.055		food
		As I 228.811	0.031	Cd I 228.801	food
At	Astatine	At I 216.225	0.010		-
		At I 224.401	0.022		-
Au	Gold	Au I 267.593	0.24	Ta II 267.590	-
		Au I 242.794	0.10	Os II 242.789	-
B	Boron	B I 249.772	0.11		food
		B I 249.676	0.062	Hf II 249.699	food
Ba	Barium	Ba II 233.527	0.062		glass
		Ba II 230.424	0.050		glass
Be	Beryllium	Be II 313.042	0.30		alloy
		Be II 313.106	0.30	Tm II 313.125	alloy
		Be I 234.860	0.051		alloy
Bi	Bismut	Bi I 306.770	0.25		alloy
		Bi I 293.868	0.24		alloy
Br	Bromine	Br I 827.241	0.43	Ag I 827.348, Nd II 827.279	thin film
Ca	Calcium	Ca II 393.366	0.39		food
		Ca II 396.846	0.60		food
		Ca I 422.672	0.53		food
Cd	Cadmium	Cd I 228.801	0.031	As I 228.811	food
Ce	Cerium	Ce II 320.171	0.27		glass
		Ce II 265.100	0.26	Be I 265.062, Ge I 265.117, Ta II 265.123	glass
Cl	Chlorine	Cl I 837.594	0.43	Gd I 837.473, Nd II 837.516, Sc II 837.706	polymer
		Cl I 725.661	0.68	Fe I 725.612, Mn I 725.573, Ni I 725.658, Sc I 725.758, Sm II 725.710, Ti I 725.727	polymer

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Element	C_{LOD} (ppm)	Transition	R_{app}	possibly interfering transitions	validation	
Co	Cobalt	2	Co I 340.511	0.30	Dy II 340.498	alloy
		2	Co I 252.136	0.15	Hf II 252.148, W I 252.131	alloy
		2	Co I 240.725	0.084		alloy
Cr	Chromium	1	Cr II 283.563	0.29		alloy
		1	Cr II 276.653	0.29		alloy
Cs	Cesium	1000	Cs I 455.528	0.63	Ce II 455.543, Cr I 455.408, Dy I 455.522, Gd II 455.498, Nd II 455.513, Ti I 455.548, U II 455.509, Zr II 455.512	thin film
Cu	Copper	0.1	Cu I 324.753	0.29		food
		0.2	Cu I 327.395	0.22		food
Dy	Dysprosium	1	Dy II 353.170	0.27		-
		2	Dy II 340.779	0.29		-
Er	Erbium	1	Er II 337.275	0.19	Ti II 337.279	-
		2	Er II 323.058	0.16		-
		2	Er II 291.036	0.20	V II 291.038	-
Eu	Europium	0.5	Eu II 397.197	0.60		-
		1	Er II 390.710	0.54		-
F	Fluorine	200000 (20%)	F I 685.603	0.80	Ce I 685.655, Cr I 685.625, Dy I 685.646, Fe I 685.516, Nd I 685.698, Sc II 685.653, Si I 685.603, Sm II 685.601, Ti II 685.573, Tm I 685.688, V II 685.648	CaF ₂
Fe	Iron	1	Fe II 259.939	0.16		food
		2	Fe II 238.203	0.082		food
Fr	Francium	50	Fr I 717.986	0.58		-
		100	Fr I 816.941	0.41		-
Ga	Galium	1	Ga I 294.363	0.12		-
		1	Ga I 287.423	0.26		-
		2	Ga I 403.297	0.65	Mn I 403.306, Tb II 403.302	-
Gd	Gadolinium	2	Gd II 342.246	0.20		-
		2	Gd II 310.050	0.20		-
Ge	Germanium	1	Ge I 265.117	0.26	Ta II 265.123	thin film
		2	Ge I 303.906	0.12	U II 303.913	thin film
Hf	Hafnium	2	Hf II 264.141	0.23		alloy
		2	Hf II 277.335	0.24		alloy
Hg	Mercury	20	Hg I 296.728	0.27	Cr I 296.764, Fe I 296.689, Hf I 296.723, Re I 296.724, Ti I 296.722, W I 296.755	-
		100	Hg I 365.015	0.39	Er II 365.040, La II 365.017, Sm II 365.017	-

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Table 1 – continued from previous page

Element	C_{LOD} (ppm)	Transition	R_{app}	possibly interfering transitions	validation	
Ho	Holmium	0.1	Ho II 341.644	0.24		-
		1	Ho II 339.895	0.34		-
I	Iodine	5000	I I 206.163	0.010	Bi I 206.162, Cr II 206.157, Os I 206.170	-
In	Indium	5	In I 325.607	0.32		thin film
		10	In I 303.934	0.12	Ge I 303.906, U II 303.925	thin film
Ir	Iridium	5	Ir I 263.970	0.22		-
		10	Ir I 284.972	0.28	Cr II 284.983	-
K	Potassium	200	K I 769.896	0.51		food
		200	K I 404.414	0.69	U II 404.441	food
La	Lanthanum	1	La II 394.910	0.45		glass
		2	La II 398.851	0.56	Yb I 398.798	glass
Li	Lithium	0.1	Li I 670.776	0.83		food
Lu	Lutetium	0.2	Lu II 261.541	0.24		-
		0.5	Lu II 290.030	0.13		-
Mg	Magnesium	0.02	Mg II 279.552	0.30		food
		0.05	Mg II 280.270	0.31		food
		0.1	Mg I 285.212	0.27		food
Mn	Manganese	0.2	Mn II 259.372	0.11		alloy
		0.2	Mn II 260.568	0.21		alloy
		0.5	Mn II 294.920	0.16		alloy
		2	Mn I 403.075	0.62		alloy
Mo	Molybdenum	1	Mo I 313.259	0.29	Er II 313.251	alloy
		1	Mo II 281.615	0.13	Er II 281.617, U II 281.598	alloy
		2	Mo I 317.034	0.30		alloy
N	Nitrogen	50000 (5%)	N I 746.831	0.59	Ru I 746.893, S I 746.858, Ta I 746.772, V I 746.831, Zr I 746.754	food
Na	Sodium	2	Na I 589.592	0.84		food
		1	Na I 588.995	0.85		food
Nb	Niobium	1	Nb II 313.078	0.29	Be II 313.042	alloy
		2	Nb II 316.339	0.29		alloy
Nd	Neodymium	5	Nd II 404.079	0.67	Ce II 404.075	glass
		10	Nd II 397.326	0.59		glass
Ni	Nickel	2	Ni I 232.003	0.038		alloy
		2	Ni I 300.248	0.19	Er II 300.240	alloy
		2	Ni I 305.081	0.20	Er II 305.085	alloy

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Element	C_{LOD} (ppm)	Transition	R_{app}	possibly interfering transitions	validation	
	2	Ni I 341.476	0.26	Ho II 341.490, Zr II 341.467	alloy	
Os	Osmium	1	Os II 248.624	0.15		-
		1	Os II 253.798	0.17	Ta II 253.795	-
		1	Os II 321.331	0.31		-
P	Phosphorus	20	P I 253.561	0.16	Co I 253.596, Fe I 253.560, Ru II 253.559, Ti II 253.587	food
		50	P I 214.914	0.012		food
		50	P I 255.326	0.17	Co I 255.333, Re II 255.360, W I 255.315	food
Pb	Lead	2	Pb I 283.305	0.27		glass
		5	Pb I 261.417	0.23	Hf II 261.429	glass
Pd	Palladium	0.5	Pd I 340.457	0.32		-
		1	Pd I 342.122	0.19		-
		1	Pd I 324.269	0.27	Y II 324.227	-
Pm	Promethium	10	Pm II 429.778	0.47	Pr II 429.776	-
Po	Polonium	5	Po I 255.800	0.14	Ta II 255.880	-
		10	Po I 300.320	0.21	Gd II 300.286, Ta II 300.299	-
Pr	Praseodymium	2	Pr II 406.280	0.57	U II 406.254	glass
		5	Pr II 390.842	0.54	Ce II 390.840	glass
Pt	Platinum	2	Pt I 306.471	0.26	Hf II 306.468	-
		2	Pt I 265.945	0.22	Ta II 265.940	-
Ra	Radium	1	Ra II 270.896	0.22	Ta II 270.926	-
Rb	Rubidium	5	Rb I 780.027	0.62		-
Re	Rhenium	1	Re II 260.849	0.22		-
		1	Re II 273.303	0.25		-
		2	Re II 256.863	0.17		-
Rh	Rhodium	1	Rh I 343.488	0.29		-
		2	Rh I 339.681	0.35	Lu II 339.706	-
Ru	Ruthenium	1	Ru II 267.875	0.26	Ta II 267.880, Zr II 267.864	-
		2	Ru II 273.434	0.24		-
S	Sulfur	10000 (1%)	S I 675.715	0.69	Co I 675.806	pyrite
Sb	Antimony	5	Sb I 276.993	0.27	Er II 277.001, Gd II 276.980	-
		10	Sb I 302.980	0.22		-
		10	Sb I 267.063	0.20	Er II 267.026	-
Sc	Scandium	0.2	Sc II 361.382	0.40		-
		0.2	Sc II 424.682	0.72		-
Se	Selenium	50	Se I 203.985	0.010		-

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Element	C_{LOD} (ppm)	Transition	R_{app}	possibly interfering transitions	validation
	100	Se I 206.278	0.010		-
Si	Silicium	Si I 251.611	0.17		food
		Si I 288.157	0.30		food
		Si I 252.850	0.11	Co II 252.861, Sb I 252.850	food
Sm	Samarium	Sm II 330.638	0.32	U II 330.589, Zr II 330.627	-
		Sm II 360.949	0.42	Pd I 360.954, Th II 360.944, Tm II 360.953	-
Sn	Tin	Sn I 283.997	0.31	U II 283.989	alloy
		Sn I 326.233	0.30	Os I 326.228	alloy
		Sn I 317.503	0.29		alloy
Sr	Strontium	Sr II 407.770	0.44		food
Ta	Tantalum	Ta II 301.254	0.26		-
		Ta II 268.518	0.28		-
		Ta II 240.063	0.081		-
Tb	Terbium	Tb II 350.914	0.34	U II 350.884	-
		Tb II 400.546	0.36		-
Tc	Technetium	Tc II 260.999	0.23		-
		Tc II 264.701	0.27		-
Te	Tellurium	Te I 238.579	0.098		glass
		Te I 238.327	0.091		glass
		Te I 317.514	0.29	Dy II 317.488, Sn I 317.503	glass
Th	Thorium	Th II 283.729	0.30	U II 283.719	-
		Th II 326.266	0.31	Er II 326.280, Sn I 326.233	-
		Th II 325.627	0.32	Dy II 325.625, In I 325.607	-
Ti	Titanium	Ti II 334.940	0.33		glass
		Ti II 323.451	0.19		glass
Tl	Thallium	Tl I 276.790	0.28		-
		Tl I 291.830	0.25	W I 291.824, Zr II 291.824	-
Tm	Thulium	Tm II 313.125	0.29	Be II 313.106	-
		Tm II 286.922	0.22		-
U	Uranium	U II 288.962	0.28		-
		U II 294.191	0.22		-
		U II 268.328	0.29		-
V	Vanadium	V II 290.881	0.19	Os I 290.905	alloy
		V II 311.071	0.25		alloy
W	Tungsten	W I 289.644	0.25	Er II 289.657	alloy

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Table 1 – continued from previous page

Element	C_{LOD} (ppm)	Transition	R_{app}	possibly interfering transitions	validation	
	20	W I 294.698	0.14	Dy II 294.706, Er II 294.661, Hf II 294.713, Nb II 294.688	alloy	
	20	W I 272.435	0.30		alloy	
Y	Yttrium	0.5	Y II 324.227	0.25	glass	
		0.5	Y II 360.073	0.41	glass	
Yb	Ytterbium	0.1	Yb II 328.936	0.26	-	
		0.5	Yb II 369.419	0.28	-	
Zn	Zinc	1	Zn I 213.857	0.0095	food	
		5	Zn I 334.501	0.33	Ce II 334.476, La II 334.456, Th II 334.487 Zr II 334.478	food
		5	Zn I 481.053	0.80		food
Zr	Zirconium	0.5	Zr II 339.198	0.32	Er II 339.198	alloy
		1	Zr II 343.822	0.30	Hf II 343.828	alloy

4. Food content and safety regulations

4.1. Minerals, oligo- and toxic elements in foodstuff

Table 2: Average fractions of minerals and oligo-elements measured for different foodstuffs on the French marked [8]. The values given in ppm mass fractions refer to the original food including moisture.

Foodstuff	Ca	Co	Cr	Cu	Li	Mg	Mn	Mo	Na	Ni	Se	Zn
Breakfast cereales	1800	0.008	0.13	2.5	0.009	480	11	0.37	3300	0.55	0.025	12
Pasta	200	0.025	0.04	1.1	0.002	120	2.5	0.034	2500	0.02	0.011	3.8
Rize semoline	220	0.010	0.06	1.2	0.004	230	4.4	0.11	3400	0.02	0.011	4.7
Milk	1400	0.001	0.02	0.12	0.006	140	0.09	0.039	450	0.07	0.015	5.1
Oils	19	0.017	0.04	0.05	0.002	45	0.06	0.011	60	0.02	0.011	0.19
Meat	150	0.008	0.05	0.78	0.002	290	0.13	0.14	1300	0.02	0.095	37
Fish	350	0.007	0.08	0.41	0.030	260	0.30	0.065	2100	0.05	0.17	5.5
Crustaceans	750	0.046	0.09	7.1	0.12	510	2.7	0.13	5400	0.23	0.011	66
Vegetables	450	0.006	0.05	0.89	0.014	170	1.8	0.17	810	0.08	0.017	2.5
Fruits	99	0.009	0.01	0.65	0.007	100	2.1	0.010	12	0.03	0.016	0.73
Chocolate	1400	0.050	0.34	2.4	0.021	370	2.4	0.17	980	0.63	0.17	8.6

Table 3: Average content of toxic elements in different foodstuffs on the French marked [8]. The values given in ppm mass fraction units refer to the original food including moisture.

Foodstuff	Al	As	Cd	Hg	Pb	Sb
Breakfast cereales	3.0	0.004	0.0017	0.015	0.010	0.0003
Pasta	0.39	0.003	0.0022	0.012	0.003	0.0003
Rize semoline	0.42	0.016	0.0032	0.005	0.005	0.0003
Milk	0.19	0.003	0.0004	0.003	0.003	0.0003
Oils	0.05	0.045	0.0004	0.003	0.005	0.0003
Meat	0.21	0.009	0.0010	0.003	0.004	0.0017
Fish	0.51	2.2	0.0016	0.062	0.023	0.0003
Crustaceans	17	1.9	0.083	0.017	0.098	0.0018
Vegetables	3.2	0.012	0.011	0.005	0.015	0.0018
Fruits	0.41	0.076	0.0018	0.003	0.010	0.0024
Chocolate	3.7	0.007	0.0004	0.042	0.028	0.0003

4.2. Food safety regulations

Table 4: Maximum content of toxic elements recommended by European and Turkish safety regulations [9, 10]. The values given in ppm mass fraction units refer to the original food including moisture.

Foodstuff	Al	As	Cd	Hg	Pb	Sb
Breakfast cereales			0.1		0.20	
Meat			0.05		0.10	
Muscle meat of fish			0.05	0.5	0.30	
Breakfast cereales			0.1		0.20	
Crustaceans			0.50		0.50	
Rize		0.2	0.2			
Breakfast cereales			0.1		0.20	
Milk					0.02	
fruits & vegetables			0.05		0.10	
Breakfast cereales			0.1		0.20	
Fungi			1		0.10	
fat & oils					3.0	
Breakfast cereales			0.1		0.20	
honey					0.10	
Food supplements			1	0.1	3.0	

5. LOD with sensitivity-improved LIBS apparatus

The apparatus used in the present experiment was designed for calibration-free LIBS measurement under controlled atmospheric conditions. It is therefore equipped with an echelle spectrometer and an observation geometry of large focusing distance. The solid angle of observation is given by

$$\Omega = \frac{\pi r^2}{f^2}, \tag{1}$$

where r is the radius and f is the focusing distance of the lens used for capturing the plasma emission. The solid angle, and thus the number of captured photons, could be increased by almost one order of magnitude by using the lens of 3 times shorter focusing length ($f = 50$ mm instead of $f = 150$ mm). Moreover, the captured plasma emission is transported via an optical fiber of $600 \mu\text{m}$ core diameter to the echelle spectrometer. According to its entrance hole of $50 \times 50 \mu\text{m}^2$, a fraction $\approx 1\%$ of the captured plasma photons enters into the spectrometer. This loss can be avoided by using an optimized optical detection system. Both improvements would thus increase the number of detected photons by a factor of 10^3 .

Another significant improvement of sensitivity is possible when using a spectrometer equipped with gratings of appropriate of blazing wavelength and a detector of optimized efficiency at the wavelength of interest. Assuming a detection system that leads to an apparatus response (see Fig 1) close to unity, the further enhancement of sensitivity scales as $1/R_{app}$. Thus, for a spectral line in the UV close to 200 nm, where $R_{app} \approx 0.01$, the number of detected photons would increase by a factor of 10^5 . According to Eqs 1 and 2 (see manuscript), the limit of detection would be reduced by $1/\sqrt{10^5} \approx 1/300$. The limits of detection being achievable with such a sensitivity-improved LIBS apparatus are displayed in Fig. 3.

H -																	He -	
Li 2	Be 0.2											B 2	C -	N 0.1%	O -	F 0.5%	Ne -	
Na 20	Mg 0.2											Al 20	Si 10	P 200	S 0.02%	Cl 0.02%	Ar -	
K 5000	Ca 0.5	Sc 5	Ti 5	V 10	Cr 20	Mn 2	Fe 10	Co 50	Ni 10	Cu 2	Zn 2	Ga 10	Ge 20	As 100	Se 200	Br 0.01%	Kr -	
Rb 100	Sr 0.5	Y 10	Zr 10	Nb 20	Mo 20	Tc 10	Ru 20	Rh 20	Pd 10	Ag 2	Cd 1	In 100	Sn 50	Sb 100	Te 100	I 20000	Xe -	
Cs 20000	Ba 2			Hf 20	Ta 10	W 200	Re 20	Os 10	Ir 100	Pt 50	Au 20	Hg 200	Tl 100	Pb 50	Bi 20	Po 50	At 50	Rn -
Fr 1000	Ra 20																	
La 20	Ce 100	Pr 50	Nd 100	Pm 200	Sm 100	Eu 10	Gd 20	Tb 20	Dy 20	Ho 2	Er 20	Tm 10	Yb 2	Lu 2				
Ac 10	Th 100	Pa ?	U 10	Np ?	Pu ?	Am ?	Cm ?	Bk ?	Cf ?	Es ?	Fm ?	Md ?	No ?	Lr ?				

Figure 3: Limits of detection in ppb mass fraction units being achievable with a sensitivity-improved LIBS apparatus.

6. Spectroscopic data

The spectroscopic data were taken in priority from the NIST database [11], and completed with data from the Kurucz database [12]. For a few transitions, data were unavailable in both databases and therefore taken from literature.

Table 5: Wavelength λ , transition probability A_{ul} , accuracy ΔA_{ul} , energy E , configuration, term and total angular momentum quantum number J of lower (index l) and upper (index u) electronic states, Stark broadening width w and shift d for $n_e = 1 \times 10^{17} \text{ cm}^{-3}$. The superscripts a , b , c and d indicate that the data were taken from the references [13], [12], [14], and [15], respectively. All other data were taken from the NIST database.

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	λ (nm)	A_{ul} (μs^{-1})	ΔA_{ul} (%)	E_l (eV)	E_u (eV)	lower level config	lower level term	J_l	upper level config	upper level term	J_u	w (pm)	d (pm)
Ac II	315.308	269	20	0.65	4.58	$6d7s$	^3D	2	$6d7p$	$^3\text{D}^\circ$	3	-	-
Ac II	299.416	282	20	0.00	4.14	$7s^2$	^1S	0	$6d7p$	$^3\text{D}^\circ$	1	-	-
Ag I	328.068	140	-	0.00	3.78	$4d^{10}5s$	^2S	1/2	$4d^{10}5p$	$^2\text{P}^\circ$	3/2	16	0.0
Ag I	338.288	130	-	0.00	3.66	$4d^{10}5s$	^2S	1/2	$4d^{10}5p$	$^2\text{P}^\circ$	1/2	40	3.9
Al I	396.152	98.5	10	0.01	3.14	$3s^23p$	$^2\text{P}^\circ$	3/2	$3s^24s$	^2S	1/2	42	24
Al I	394.400	49.9	10	0.00	3.14	$3s^23p$	$^2\text{P}^\circ$	1/2	$3s^24s$	^2S	1/2	42	24
Al I	308.215	58.7	10	0.00	4.02	$3s^23p$	$^2\text{P}^\circ$	1/2	$3s^23d$	^2D	3/2	76	18
As I	234.984	310	40	1.31	6.59	$4s^24p^3$	$^2\text{D}^\circ$	3/2	$4s^24p^2(^3\text{P})5s$	^2P	1/2	14	0.0
As I	228.811	280	40	1.35	6.77	$4s^24p^3$	$^2\text{D}^\circ$	5/2	$4s^24p^2(^3\text{P})5s$	^2P	3/2	14	0.0
At I	216.225	313 ^a	-	0.00	5.73	$6p^5$	$^2\text{P}^\circ$	3/2	$6p^4(^3\text{P})7s$	^4P	3/2	-	-
At I	224.401	27.8 ^a	-	0.00	5.52	$6p^5$	$^2\text{P}^\circ$	3/2	$6p^4(^3\text{P})7s$	^4P	5/2	-	-
Au I	267.593	164	5	0.00	4.63	$5d^{10}6s$	^2S	1/2	$5d^{10}6p$	$^2\text{P}^\circ$	1/2	1.4	5.6
Au I	242.794	198	10	0.00	5.11	$5d^{10}6s$	^2S	1/2	$5d^{10}6p$	$^2\text{P}^\circ$	3/2	1.4	5.6
B I	249.772	168	7	0.00	4.96	$2s^22p$	$^2\text{P}^\circ$	3/2	$2s^23s$	^2S	1/2	12	7.0
B I	249.676	84.0	7	0.00	4.96	$2s^22p$	$^2\text{P}^\circ$	1/2	$2s^23s$	^2S	1/2	12	7.0
Ba II	233.526	2655	-	0.70	6.01	$5d$	^2D	5/2	$4f$	$^2\text{F}^\circ$	7/2	17	-1.5
Ba II	230.424	3316	-	0.60	5.98	$5d$	^2D	3/2	$4f$	$^2\text{F}^\circ$	5/2	17	-1.4
Be II	313.042	113	1	0.00	3.96	$1s^22s$	^2S	1/2	$1s^22p$	$^2\text{P}^\circ$	3/2	-	-
Be II	313.106	113	1	0.00	3.96	$1s^22s$	^2S	1/2	$1s^22p$	$^2\text{P}^\circ$	1/2	-	-
Be I	234.860	552	7	0.00	5.28	$1s^22s^2$	^1S	0	$1s^22s2p$	$^1\text{P}^\circ$	1	-	-
Bi I	306.770	167	-	0.00	4.04	$6p^3$	$^4\text{S}^\circ$	3/2	$6p^2(^3\text{P}_0)7s$	$^2[0]$	1/2	23	12
Bi I	293.829	123	-	1.91	6.13	$6p^3$	$^2\text{D}^\circ$	5/2	$6p^2(^3\text{P}_2)7s$	$^2[2]$	3/2	100	30
Br I	827.241	35.0	20	7.87	9.36	$4s^24p^4(^3\text{P}_2)5s$	$^2[2]$	5/2	$4s^24p^4(^3\text{P}_2)5p$	$^2[3]^\circ$	7/2	140	35
Ca II	393.366	147	25	0.00	3.15	$3p^64s$	^2S	1/2	$3p^64p$	$^2\text{P}^\circ$	3/2	20	-4.0
Ca II	396.846	140	25	0.00	3.12	$3p^64s$	^2S	1/2	$3p^64p$	$^2\text{P}^\circ$	1/2	20	-4.0
Ca I	422.672	218	10	0.00	2.93	$3p^64s^2$	^1S	0	$3p^64s4p$	$^1\text{P}^\circ$	1	20	2.9
Cd I	228.802	530	25	0.00	5.42	$4d^{10}5s^2$	^1S	0	$4d^{10}5s5p$	$^1\text{P}^\circ$	1	3.0	0.0

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Table 5 – continued from previous page

	λ (nm)	A_{ul} (μs^{-1})	ΔA_{ul} (%)	E_l (eV)	E_u (eV)	lower level config	term	J_l	upper level config	term	J_u	w (pm)	d (pm)	
	Ce II	320.171	349 ^b	-	0.86	4.73	4f5d(³ H°)6s	⁴ H°	13/2	4f6s(³ F°)6p	⁴ G	11/2	-	-
	Ce II	265.100	2079 ^b	-	1.21	5.89	4f(² F°)6s ²	² F°	5/2	5d ² (¹ G)6s	² G	7/2	-	-
	Cl I	837.594	28.0	40	8.92	10.40	3s ² 3p ⁴ (³ P)4s	⁴ P	5/2	3s ² 3p ⁴ (³ P)4p	⁴ D°	7/2	154	0.0
	Cl I	725.661	15.0	40	8.92	10.63	3s ² 3p ⁴ (³ P)4s	⁴ P	5/2	3s ² 3p ⁴ (³ P)4p	⁴ S°	3/2	-	-
	Co I	340.511	100	20	0.43	4.07	3d ⁸ (³ F)4s	b ⁴ F	9/2	3d ⁸ (³ F)4p	y ⁴ F°	9/2	-	-
	Co I	252.136	300	40	0.00	4.92	3d ⁷ 4s ²	a ⁴ F	9/2	3d ⁷ (⁴ F)4s4p(¹ P°)	x ⁴ D°	7/2	-	-
	Co I	240.725	360	25	0.00	5.15	3d ⁷ 4s ²	a ⁴ F	9/2	3d ⁷ (⁴ F)4s4p(¹ P°)	x ⁴ G°	11/2	5.0	2.0
	Cr II	283.563	200	25	1.55	5.92	3d ⁴ (⁵ D)4s	a ⁶ D	9/2	3d ⁴ (⁵ D)4p	z ⁶ F°	11/2	10	0.0
	Cr II	276.653	222	-	1.55	6.03	3d ⁴ (⁵ D)4s	a ⁶ D	9/2	3d ⁴ (⁵ D)4p	z ⁶ P°	7/2	4.0	0.0
	Cs I	455.528	1.84	2	0.00	2.72	5p ⁶ 6s	² S	1/2	5p ⁶ 7p	² P°	3/2	500	200
	Cu I	324.753	140	2	0.00	3.82	3d ¹⁰ 4s	² S	1/2	3d ¹⁰ 4p	² P°	3/2	7.0	3.0
	Cu I	327.395	138	2	0.00	3.79	3d ¹⁰ 4s	² S	1/2	3d ¹⁰ 4p	² P°	1/2	7.0	3.0
	Dy II	353.170	156	-	0.00	3.51	4f ¹⁰ (⁵ I ₈)6s _{1/2}	(8,1/2)	17/2	4f ¹⁰ (⁵ I)6p	⁶ K°	19/2	-	-
	Dy II	340.779	48.8	-	0.00	3.64	4f ¹⁰ (⁵ I ₈)6s _{1/2}	(8,1/2)	17/2	4f ¹⁰ (⁵ I)6p	⁶ I°	17/2	-	-
	Er II	337.275	130	-	0.00	3.68	4f ¹² (³ H ₆)6s _{1/2}	(6,1/2)	13/2	4f ¹² (³ H ₆)6p _{3/2}	(6,3/2)°	15/2	-	-
	Er II	323.058	150	-	0.05	3.89	4f ¹² (³ H ₆)6s _{1/2}	(6,1/2)	11/2			11/2	-	-
	Er II	291.036	366	-	0.85	5.11	4f ¹¹ 6s ²	⁴ I°	15/2			15/2	-	-
	Eu II	397.197	89.0	-	0.21	3.33	4f ⁷ (⁸ S°)6s	a ⁷ S°	3	4f ⁷ (⁸ S° _{7/2})6p _{3/2}	(7/2,3/2)	4	-	-
	Eu II	390.710	137	-	0.21	3.38	4f ⁷ (⁸ S°)6s	a ⁷ S°	3	4f ⁷ (⁸ S° _{7/2})6p _{3/2}	(7/2,3/2)	2	-	-
	F I	685.603	48.7	20	12.70	14.50	2s ² 2p ⁴ (³ P)3s	⁴ P	5/2	2s ² 2p ⁴ (³ P)3p	⁴ D°	7/2	-	-
	Fe II	259.939	235	10	0.00	4.77	3d ⁶ (⁵ D)4s	a ⁶ D	9/2	3d ⁶ (⁵ D)4p	z ⁶ D°	9/2	3.0	0.0
	Fe II	238.203	313	10	0.00	5.20	3d ⁶ (⁵ D)4s	a ⁶ D	9/2	3d ⁶ (⁵ D)4p	z ⁶ F°	11/2	10	0.0
	Fr I	717.986	47.8	-	0.00	1.73	7s	² S	1/2	7p	² P°	3/2	-	-
	Fr I	816.941	32.2	-	0.00	1.52	7s	² S	1/2	7p	² P°	1/2	-	-
	Ga I	294.363	134	10	0.10	4.31	3d ¹⁰ 4s ² 4p	² P°	3/2	4s ² 4d	² D	5/2	-	-
	Ga I	287.423	117	10	0.00	4.31	3d ¹⁰ 4s ² 4p	² P°	1/2	4s ² 4d	² D	3/2	-	-
	Ga I	403.298	48.5	10	0.00	3.07	3d ¹⁰ 4s ² 4p	² P°	1/2	4s ² 5s	² S	1/2	-	-
	Gd II	342.246	118 ^b	-	0.24	3.86	4f ⁷ (⁸ S°)5d(⁹ D°)6s	¹⁰ D°	13/2	4f ⁷ (⁸ S°)5d(⁹ D°)6p	¹⁰ F	15/2	-	-
	Gd II	310.050	169 ^b	-	0.24	4.24	4f ⁷ (⁸ S°)5d(⁹ D°)6s	¹⁰ D°	13/2	4f ⁷ (⁸ S°)5d(⁹ D°)6p	¹⁰ P	11/2	-	-
	Ge I	265.117	200	-	0.17	4.85	4s ² 4p ²	³ P	2	4s ² 4p5s	³ P°	2	-	-
	Ge I	303.906	280	-	0.88	4.96	4s ² 4p ²	¹ D	2	4s ² 4p5s	¹ P°	1	17	11
	Hf II	264.141	372 ^b	-	1.04	5.73	5d ² (³ F)6s	a ⁴ F	9/2	5d ² (³ F)6p	z ⁴ G°	11/2	14	2.2
	Hf II	277.335	141 ^b	-	0.79	5.26	5d ² (³ F)6s	a ⁴ F	7/2	5d ² (³ F)6p	z ⁴ G°	9/2	12	2.2

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	λ	A_{ul}	ΔA_{ul}	E_l	E_u	lower level			upper level			w	d
	(nm)	(μs^{-1})	(%)	(eV)	(eV)	config	term	J_l	config	term	J_u	(pm)	(pm)
Hg I	296.728	46.0	40	4.67	8.84	$5d^{10}6s6p$	$^3\text{P}^\circ$	0	$5d^{10}6s6d$	^3D	1	-	-
Hg I	365.484	18.4	15	5.46	8.85	$5d^{10}6s6p$	$^3\text{P}^\circ$	2	$5d^{10}6s6d$	^3D	2	-	-
Ho II	341.644	974 ^b	-	0.08	3.71	$4f^{11}(^4\text{I}_{15/2}^\circ)6s_{1/2}$	$(15/2,1/2)^\circ$	7	$4f^{11}(^4\text{I}_{15/2}^\circ)6p_{3/2}$	$(15/2,3/2)$	7	-	-
Ho II	339.895	63.5 ^b	-	0.00	3.65	$4f^{11}(^4\text{I}_{15/2}^\circ)6s_{1/2}$	$(15/2,1/2)^\circ$	8	$4f^{11}(^4\text{I}_{15/2}^\circ)6p_{3/2}$	$(15/2,3/2)$	8	-	-
II	206.162	3.0	-	0.94	6.95	$5s^25p^5$	$^2\text{P}^\circ$	1/2	$5s^25p^4(^3\text{P}_2)6s$	$^2[2]$	3/2	-	-
In I	325.607	130	-	0.27	4.08	$5s^25p$	$^2\text{P}^\circ$	3/2	$5s^25d$	^2D	5/2	134	-17
In I	303.934	111	-	0.00	4.08	$5s^25p$	$^2\text{P}^\circ$	1/2	$5s^25d$	^2D	3/2	100	-13
Ir I	263.970	46.9	7	0.00	4.70	$5d^76s^2$	$a^4\text{F}$	9/2	$5d^76s(^5\text{F})6p$	$z^4\text{F}^\circ$	9/2	-	-
Ir I	284.972	22.6	10	0.00	4.35	$5d^76s^2$	$a^4\text{F}$	9/2	$5d^76s(^5\text{F})6p$	$z^6\text{G}^\circ$	9/2	-	-
K I	769.896	37.5	5	0.00	1.61	$3p^64s$	^2S	1/2	$3p^64p$	$^2\text{P}^\circ$	1/2	105	24
K I	404.414	1.16	-	0.00	3.06	$3p^64s$	^2S	1/2	$3p^65p$	$^2\text{P}^\circ$	3/2	124	47
La II	394.910	147	10	0.40	3.54	$5d6s$	$a^3\text{D}$	3	$5d6p$	$x^3\text{F}^\circ$	4	17	0.0
La II	398.851	97.0	15	0.40	3.51	$5d6s$	$a^3\text{D}$	3	$5d6p$	$y^3\text{D}^\circ$	3	-	-
Li I	670.776	36.9	1	0.00	1.85	$1s^22s$	^2S	1/2	$1s^22p$	$^2\text{P}^\circ$	3/2	39	-2.7
Lu II	261.541	453	-	0.00	4.74	$6s^2$	^1S	0	$6s6p$	$^1\text{P}^\circ$	1	-	-
Lu II	290.030	380 ^b	-	1.54	5.82	$5d6s$	^3D	2	$5d6p$	$^3\text{D}^\circ$	2	-	-
Mg II	279.552	260	5	0.00	4.43	$2p^63s$	^2S	1/2	$2p^63p$	$^2\text{P}^\circ$	3/2	4.0	0.0
Mg II	280.270	257	5	0.00	4.42	$2p^63s$	^2S	1/2	$2p^63p$	$^2\text{P}^\circ$	1/2	4.0	0.0
Mg I	285.212	491	7	0.00	4.35	$2p^63s^2$	^1S	0	$3s3p$	$^1\text{P}^\circ$	1	11	4.2
Mn II	259.372	276	5	0.00	4.78	$3d^5(^6\text{S})4s$	$a^7\text{S}$	3	$3d^5(^6\text{S})4p$	$z^7\text{P}^\circ$	3	4.5	-1.0
Mn II	260.568	269	5	0.00	4.76	$3d^5(^6\text{S})4s$	$a^7\text{S}$	3	$3d^5(^6\text{S})4p$	$z^7\text{P}^\circ$	2	2.1	1.7
Mn II	294.920	196	5	1.17	5.38	$3d^5(^6\text{S})4s$	$a^5\text{S}$	2	$3d^5(^6\text{S})4p$	$z^5\text{P}^\circ$	3	4.4	1.6
Mn I	403.075	17.0	20	0.00	3.08	$3d^54s^2$	$a^6\text{S}$	5/2	$3d^5(^6\text{S})4s4p(^3\text{P}^\circ)$	$z^6\text{P}^\circ$	7/2	12	0.0
Mo I	313.259	179	10	0.00	3.96	$4d^5(^6\text{S})5s$	$a^7\text{S}$	3	$4d^45s(^6\text{D})5p$	$y^7\text{P}^\circ$	4	5.0	0.0
Mo II	281.615	227 ^b	-	1.67	6.07	$4d^4(^5\text{D})5s$	$a^6\text{D}$	9/2	$4d^4(^5\text{D})5p$	$z^6\text{F}^\circ$	11/2	4.0	0.0
Mo I	317.034	137	10	0.00	3.91	$4d^5(^6\text{S})5s$	$a^7\text{S}$	3	$4d^45s(^6\text{D})5p$	$y^7\text{P}^\circ$	3	5.0	0.0
N I	746.831	19.6	10	10.34	12.00	$2s^22p^2(^3\text{P})3s$	^4P	5/2	$2s^22p^2(^3\text{P})3p$	$^4\text{S}^\circ$	3/2	106	32
Na I	589.592	61.4	2	0.00	2.10	$2p^63s$	^2S	1/2	$2p^63p$	$^2\text{P}^\circ$	1/2	44	13
Na I	588.995	61.6	2	0.00	2.10	$2p^63s$	^2S	1/2	$2p^63p$	$^2\text{P}^\circ$	3/2	44	13
Nb II	313.078	159 ^b	-	0.44	4.40	$4d^3(^4\text{F})5s$	$a^5\text{F}$	4	$4d^3(^4\text{F})5p$	$z^5\text{G}^\circ$	5	10	0.0
Nb II	316.339	135 ^b	-	0.38	4.29	$4d^3(^4\text{F})5s$	$a^5\text{F}$	3	$4d^3(^4\text{F})5p$	$z^5\text{G}^\circ$	4	5.0	0.0
Nd II	404.079	38.2 ^b	-	0.18	3.25	$4f^4(^5\text{I})6s$	^6I	11/2	$4f^4(^5\text{I})6p$		13/2	-	-
Nd II	397.326	54.0 ^b	-	0.63	3.75	$4f^4(^5\text{I})6s$	^6I	17/2	$4f^4(^5\text{I})6p$	$^6\text{I}^\circ$	17/2	-	-

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Table 5 – continued from previous page

	λ (nm)	A_{ul} (μs^{-1})	ΔA_{ul} (%)	E_l (eV)	E_u (eV)	lower level config	term	J_l	upper level config	term	J_u	w (pm)	d (pm)	
	Ni I	232.003	690	25	0.00	5.34	$3d^8(^3F)4s^2$	3F	4	$3d^8(^3F)4s4p(^1P^\circ)$	$^3G^\circ$	5	3.5	1.5
	Ni I	300.248	80.0	20	0.03	4.15	$3d^9(^2D)4s$	3D	3	$3d^8(^3F)4s4p(^3P^\circ)$	$^3D^\circ$	3	7.0	0.0
	Ni I	305.081	60.0	20	0.03	4.09	$3d^9(^2D)4s$	3D	3	$3d^8(^3F)4s4p(^3P^\circ)$	$^3F^\circ$	4	2.0	0.0
	Ni I	341.476	55.0	25	0.03	3.66	$3d^9(^2D)4s$	3D	3	$3d^9(^2D)4p$	$^3F^\circ$	4	7.6	0.4
	Os II	248.624	2816 ^b	-	0.45	5.43	$5d^6(^5D)6s$	a^6D	7/2	$5d^6(^5D)6p$	z^6D°	7/2	-	-
	Os II	253.798	1235 ^b	-	0.00	4.88	$5d^6(^5D)6s$	a^6D	9/2	$5d^56s6p$	$^8P^\circ$	7/2	-	-
	Os II	321.331	1230 ^b	-	1.64	5.49	$5d^7$	4F	7/2	$5d^6(^5D)6p$	z^6D°	9/2	-	-
	P I	253.561	95.0	25	2.32	7.21	$3s^23p^3$	$^2P^\circ$	3/2	$3s^23p^2(^3P)4s$	2P	3/2	10	2.0
	P I	214.914	318	25	1.41	7.18	$3s^23p^3$	$^2D^\circ$	3/2	$3s^23p^2(^3P)4s$	2P	1/2	-	-
	P I	255.326	71.0	25	2.32	7.18	$3s^23p^3$	$^2P^\circ$	1/2	$3s^23p^2(^3P)4s$	2P	1/2	10	2.0
	Pb I	283.305	49.0	20	0.00	4.38	$6s^26p^2$	(1/2,1/2)	0	$6s^26p7s$	(1/2,1/2) ^o	1	18	10
	Pb I	261.417	198	20	0.97	5.71	$6s^26p^2$	(3/2,1/2)	1	$6s^26p(^2P^\circ_{1/2})6d$	$^2[3/2]^\circ$	2	40	-4.1
	Pd I	340.457	134	-	0.81	4.45	$4d^9(^2D_{5/2})5s$	$^2[5/2]$	3	$4d^9(^2D_{5/2})5p$	$^2[7/2]^\circ$	4	42	-4.2
	Pd I	342.122	168 ^b	-	0.96	4.58	$4d^9(^2D_{5/2})5s$	$^2[5/2]$	2	$4d^9(^2D_{5/2})5p$	$^2[5/2]^\circ$	2	40	0.0
	Pd I	324.269	77.0	-	0.81	4.64	$4d^9(^2D_{5/2})5s$	$^2[5/2]$	3	$4d^9(^2D_{5/2})5p$	$^2[5/2]^\circ$	3	40	0.0
16	Pm II	429.778	68.8 ^c	-	0.00	2.88	$4f^5(^6H^\circ)6s$	$^7H^\circ$	2	$4f^5(^6H)6p$	7I	3	-	-
	Po I	255.800	71.8 ^d	-	0.00	4.85	$6p^4$	3P	2	$6p^3(^4S^\circ)7s$	$^5S^\circ$	2	-	-
	Po I	300.320	37.9 ^d	-	0.93	5.06	$6p^4$	3P	0	$6p^3(^4S^\circ)7s$	$^3S^\circ$	1	-	-
	Pr II	406.280	100 ^b	-	0.42	3.47	$4f^3(^4I^\circ_{13/2})6s_{1/2}$	(13/2,1/2) ^o	6	$4f^3(^4I^\circ)6p$	3I	7	-	-
	Pr II	390.842	89.3 ^b	-	0.00	3.17	$4f^3(^4I^\circ_{9/2})6s_{1/2}$	(9/2,1/2) ^o	4	$4f^3(^4I^\circ)6p$	5H	3	-	-
	Pt I	306.471	65.9	10	0.00	4.04	$5d^96s$	3D	3	$5d^96p$	a^3P°	2	-	-
	Pt I	265.945	99.0	10	0.00	4.66	$5d^96s$	3D	3	$5d^96p$	$^3F^\circ$	4	-	-
	Ra II	270.896	370	2	1.50	6.07	$6d$	2D	3/2	$5f$	$^2F^\circ$	5/2	-	-
	Rb I	780.027	38.1	-	0.00	1.59	$4p^65s$	2S	1/2	$4p^65p$	$^2P^\circ$	3/2	200	0.0
	Re II	260.849	4386 ^b	-	1.78	6.53	$5d^46s^2$	a^5D	2	$5d^5(^6S)6p$	z^5P°	2	-	-
	Re II	273.303	3431 ^b	-	2.14	6.67	$5d^5(^6S)6s$	a^5S	2	$5d^5(^6S)6p$	z^5P°	3	-	-
	Re II	256.863	2626 ^b	-	1.85	6.67	$5d^46s^2$	a^5D	4	$5d^5(^6S)6p$	z^5P°	3	-	-
	Rh I	343.488	133 ^b	-	0.00	3.61	$4d^8(^3F)5s$	a^4F	9/2	$4d^8(^3F)5p$	z^4G°	11/2	-	-
	Rh I	339.681	65.0 ^b	-	0.00	3.65	$4d^8(^3F)5s$	a^4F	9/2	$4d^8(^3F)5p$	z^4F°	9/2	-	-
	Ru II	267.875	1507 ^b	-	1.13	5.76	$4d^6(^5D)5s$	6D	9/2	$4d^6(^5D)5p$	$^6D^\circ$	9/2	-	-
	Ru II	273.434	927 ^b	-	1.26	5.79	$4d^6(^5D)5s$	6D	7/2	$4d^6(^5D)5p$	$^6D^\circ$	7/2	-	-
	S I	675.715	7.2	30	7.87	9.70	$3s^23p^3(^4S^\circ)4p$	5P	3	$3s^23p^3(^4S^\circ)5d$	$^5D^\circ$	4	500	0.0
	Sb I	276.993	189 ^b	-	1.22	5.70	$5p^3$	$^2D^\circ$	5/2	$5p^2(^3P)6s$	4P	3/2	-	-

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Table 5 – continued from previous page

	λ (nm)	A_{ul} (μs^{-1})	ΔA_{ul} (%)	E_l (eV)	E_u (eV)	lower level config	term	J_l	config	upper level term	J_u	w (pm)	d (pm)	
	Sb I	302.980	262 ^b	-	2.03	6.12	5p ³	2P ^o	1/2	5p ² (³ P)6s	2P	3/2	165	76
	Sb I	267.063	75.6 ^b	-	1.06	5.70	5p ³	2D ^o	3/2	5p ² (³ P)6s	4P	3/2	-	-
	Sc II	361.382	148	10	0.02	3.45	3p ⁶ 3d4s	³ D	3	3p ⁶ 3d4p	³ F ^o	4	-	-
	Sc II	424.682	129	7	0.32	3.23	3p ⁶ 3d4s	¹ D	2	3p ⁶ 3d4p	¹ D ^o	2	-	-
	Se I	203.985	414 ^b	-	0.25	6.32	4p ⁴	³ P	1	4p ³ (⁴ S ^o)5s	³ S ^o	1	-	-
	Se I	206.278	158 ^b	-	0.31	6.32	4p ⁴	³ P	0	4p ³ (⁴ S ^o)5s	³ S ^o	1	-	-
	Si I	251.611	168	15	0.03	4.95	3s ² 3p ²	³ P	2	3s ² 3p4s	³ P ^o	2	11	7.0
	Si I	288.157	217	15	0.78	5.08	3s ² 3p ²	¹ D	2	3s ² 3p4s	¹ P ^o	1	14	9.8
	Si I	252.850	90.4	15	0.03	4.93	3s ² 3p ²	³ P	2	3s ² 3p4s	³ P ^o	1	11	7.0
	Sm II	330.638	50.5 ^b	-	0.48	4.23	4f ⁶ (⁷ F)6s	⁸ F	13/2	4f ⁵ 5d6s?		13/2	-	-
	Sm II	360.949	58.0	-	0.28	3.71	4f ⁶ (⁷ F)6s	⁸ F	9/2	4f ⁵ 5d6s?		11/2	-	-
	Sn I	283.997	170	-	0.42	4.79	5s ² 5p ²	³ P	2	5s ² 5p6s	³ P ^o	2	23	9.8
	Sn I	326.233	270	-	1.07	4.87	5s ² 5p ²	¹ D	2	5s ² 5p6s	¹ P ^o	1	20	7.4
	Sn I	317.503	100	-	0.42	4.33	5s ² 5p ²	³ P	2	5s ² 5p6s	³ P ^o	1	23	12
	Sr II	407.770	141	2	0.00	3.04	4p ⁶ 5s	² S	1/2	4p ⁶ 5p	² P ^o	3/2	41	-3.4
17	Ta II	301.254	1648 ^b	-	0.66	4.78	5d ² 6s ²	a ³ P	1	5d ⁴	⁵ F ^o	2	-	-
	Ta II	268.518	4063 ^b	-	0.51	5.13	5d ² 6s ²	a ³ P	0	5d ⁴	^o	1	-	-
	Ta II	240.063	3974 ^b	-	0.77	5.93	5d ³ (⁴ F)6s	a ⁵ F	5	5d ⁴	^o	6	-	-
	Tb II	350.914	53.7	-	0.00	3.53	4f ⁹ (⁶ H _{15/2} ^o)6s _{1/2}	(15/2, 1/2) ^o	8	4f ⁹ (⁶ H _{15/2} ^o)6p _{3/2}	(15/2, 3/2)	9	-	-
	Tb II	400.546	90.8 ^b	-	0.13	3.22	4f ⁹ (⁶ H _{15/2} ^o)6s _{1/2}	(15/2, 1/2) ^o	7	4f ⁹ (⁶ H _{15/2} ^o)6p _{3/2}	(15/2, 1/2)	8	-	-
	Tc II	260.999	380	0.00	4.75	4d ⁵ (⁶ S)5s	a ⁷ S	3	4d ⁵ (⁶ S)5p	z ⁷ P ^o	3	-	-	
	Tc II	264.701	370	-	0.00	4.68	4d ⁵ (⁶ S)5s	a ⁷ S	3	4d ⁵ (⁶ S)5p	z ⁷ P ^o	2	-	-
	Te I	238.579	270 ^b	-	0.59	5.78	5p ⁴	³ P	1	5p ³ (⁴ S ^o)6s	³ S ^o	1	-	-
	Te I	238.327	215 ^b	-	0.58	5.78	5p ⁴	³ P	0	5p ³ (⁴ S ^o)6s	³ S ^o	1	-	-
	Te I	317.514	206 ^b	-	2.88	6.78	5p ⁴	¹ S	0	5p ³ (² D ^o)6s	³ D ^o	1	-	-
	Th II	283.729	166 ^b	-	0.77	5.14	6d ² (³ F)7s	⁴ F	9/2	6d ² (³ F)7p	⁴ G ^o	11/2	-	-
	Th II	326.266	58.7 ^b	-	0.76	4.56	5f6d(³ H ^o)7s	⁴ H ^o	7/2	5f6d(¹ G ^o)7p		7/2	-	-
	Th II	325.627	94.5 ^b	-	1.15	4.95	5f6d(¹ G ^o)7s		9/2	5f ² (³ F)6d		11/2	-	-
	Ti II	334.940	168	20	0.05	3.75	3d ² (³ F)4s	a ⁴ F	9/2	3d ² (³ F)4p	z ⁴ G ^o	11/2	11	0.1
	Ti II	323.451	171	10	0.05	3.88	3d ² (³ F)4s	a ⁴ F	9/2	3d ² (³ F)4p	z ⁴ F ^o	9/2	12	0.0
	Tl I	276.790	126	25	0.00	4.48	6s ² 6p	² P ^o	1/2	6s ² 6d	² D	3/2	-	-
	Tl I	291.830	42.0	25	0.97	5.21	6s ² 6p	² P ^o	3/2	6s ² 7d	² D	5/2	-	-
	Tm II	313.125	106	-	0.00	3.96	4f ¹³ (² F _{7/2} ^o)6s _{1/2}	(7/2, 1/2) ^o	4	4f ¹² 5d6s		5	-	-

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Table 5 – continued from previous page

	λ (nm)	A_{ul} (μs^{-1})	ΔA_{ul} (%)	E_l (eV)	E_u (eV)	lower level config	term	J_l	config	upper level term	J_u	w (pm)	d (pm)
Tm II	286.922	491 ^b	-	1.54	5.86	$4f^{12}(^3\text{H})6s^2$	^3H	6	$4f^{12}5d6p$	$^{\circ}$	7	-	-
U II	288.962	62.5 ^b	-	0.04	4.33	$5f^36d^2$	^6L	11/2			11/2	-	-
U II	294.191	190 ^b	-	0.69	4.90	$5f^36d7s$	^6K	13/2			15/2	-	-
U II	268.328	392 ^b	-	1.03	5.65	$5f^36d7s$	^4I	13/2			13/2	-	-
V II	290.881	177	10	0.39	4.65	$3d^3(^4\text{F})4s$	$a^5\text{F}$	5	$3d^3(^4\text{F})4p$	$z^5\text{D}^{\circ}$	4	-	-
V II	311.071	158	10	0.35	4.33	$3d^3(^4\text{F})4s$	$a^5\text{F}$	3	$3d^3(^4\text{F})4p$	$z^5\text{G}^{\circ}$	4	10	0.0
W I	289.644	130	40	0.37	4.65	$5d^5(^6\text{S})6s$	^7S	3		$^{\circ}$	2	-	-
W I	294.698	82.0	15	0.37	4.57	$5d^5(^6\text{S})6s$	^7S	3		$^{\circ}$	3	-	-
W I	272.435	105	15	0.37	4.92	$5d^5(^6\text{S})6s$	^7S	3		$^{\circ}$	3	-	-
Y II	324.227	203	10	0.18	4.00	$4d5s$	$a^3\text{D}$	3	$4d5p$	$y^3\text{P}^{\circ}$	2	8.0	0.0
Y II	360.073	138	10	0.18	3.62	$4d5s$	$a^3\text{D}$	3	$4d5p$	$z^3\text{D}^{\circ}$	3	7.0	0.0
Yb II	328.936	162	-	0.00	3.77	$4f^{14}6s$	^2S	1/2	$4f^{14}6p$	$^2\text{P}^{\circ}$	3/2	-	-
Yb II	369.419	123	-	0.00	3.36	$4f^{14}6s$	^2S	1/2	$4f^{14}6p$	$^2\text{P}^{\circ}$	1/2	-	-
Zn I	213.857	714	7	0.00	5.80	$3d^{10}4s^2$	^1S	0	$3d^{10}4s4p$	$^1\text{P}^{\circ}$	1	2.0	0.0
Zn I	334.501	170	15	4.08	7.78	$3d^{10}4s4p$	$^3\text{P}^{\circ}$	2	$3d^{10}4s4d$	^3D	3	96	-11
Zn I	481.053	70.0 ^b	-	4.08	6.65	$3d^{10}4s4p$	$^3\text{P}^{\circ}$	2	$3d^{10}4s5s$	^3S	1	64	38
Zr II	339.198	140 ^b	-	0.16	3.82	$4d^2(^3\text{F})5s$	$a^4\text{F}$	9/2	$4d^2(^3\text{F})5p$	$z^4\text{G}^{\circ}$	11/2	12	1.0
Zr II	343.822	115 ^b	-	0.09	3.70	$4d^2(^3\text{F})5s$	$a^4\text{F}$	7/2	$4d^2(^3\text{F})5p$	$z^4\text{G}^{\circ}$	9/2	12	1.0

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