Title: **The geometrowave potential quantified and unified chemical properties**

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To date, size-dependent properties for atoms, ions, clusters, molecules, nanoparticles (or NPs) haven't been quantitatively predicted, differentiated, and unified, leaving many questions long-unanswered in chemistry. This work has introduced a geometrowave-number ($\tilde{\nu}_{GW}$) and GW-potential (μ_{GW}) to quantitatively predict, compare, and unify these particles' size-dependent properties. Such geometry-quantized chemical properties quantify the energy (or spontaneity) in self-assemble bonding, macromolecules' folding–unfolding, surface defects' reactivity, ions' GW-electronegativity, and NPs' redox change.

If predicting 64 Au-NPs (each 2-nm large) spontaneous self-assembly to an 8-nm NP, directly (*Route-A*) or stepwise (*Route B* + *Route C*) (**Fig. 1a**), each route's Gibbs free energy change[1] $\Delta G < 0$, supposedly. In chemical thermodynamics, however, NP formation's enthalpy (ΔH_f), entropy (ΔS_f), and ΔG_f ($\approx \Delta H_f - T\Delta S_f$) are unquantified or undefined, leaving self-assemblies[2-7] never predicted and compared quantitatively.

To tackle many such problems in the thermodynamics- and quantum mechanics (QM)-based general chemistry, let's quantize the zero-dimensional (0D), 1D-, 2D- and 3D-particles' Surface Area-to-Volume (SA/V) ratio (see the **Extended Data Table S1**) into a geometrowave-number ($\tilde{\nu}_{GW}$) with a unit of (length^{-1}). Thus, at T = 298.15 (^{o}K) and 1 (atm), the GW-potential $\mu_f{}^o{}_{GW} = hc{\cdot}\tilde{\nu}_{GW}$, where the c = speed of light, h = Planck constant, and $hc \approx 1.24$ (keV·nm). Therefore,

$$\Delta\mu_f{}^o{}_{GW(Route\text{-}A)} = \mu_f{}^o{}_{GW(8nm\text{-}NP)} - 64\mu_f{}^o{}_{GW(2nm\text{-}NPs)}$$

$$= \{6/8 - 64(6/2)\}\hbar c = -237.2 \text{ (keV)},$$

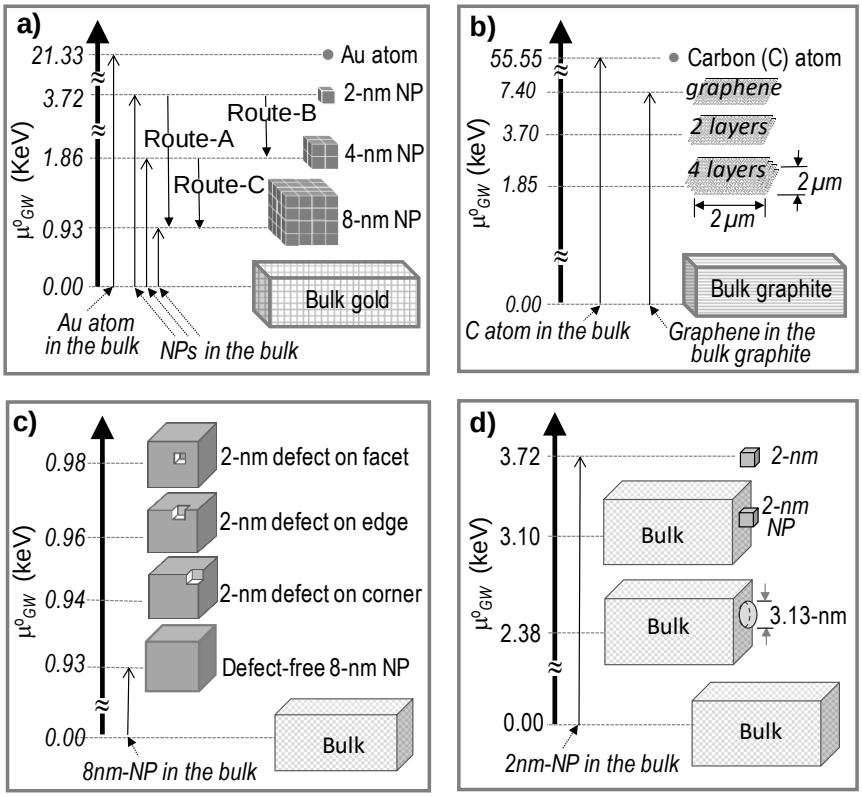


Fig. 1. The μ^o_{GW} values. For the Au-NPs self-assembly (**a**), the graphene-layers (**b**), a 2-nm surface-defects on an 8-nm NP (**c**), and a 2-nm NP's adsorption and sintering on a large surface (**d**).

$\Delta\mu_f{}^o{}_{GW(Route\text{-}B)} = 8\mu_f{}^o{}_{GW(4nm\text{-}NPs)} - 64\mu_f{}^o{}_{GW(2nm\text{-}NPs)} = \{8(6/4) - 64(6/2)\}\hbar c = -223.2$ (keV),

$\Delta\mu_f{}^o{}_{GW(Route\text{-}C)} = \mu_f{}^o{}_{GW(8nm\text{-}NP)} - 8\mu_f{}^o{}_{GW(4nm\text{-}NPs)} = \{6/8 - 8(6/4)\}\hbar c = -14.0$ (keV), and

$\Delta\mu_f{}^o{}_{GW(Route\text{-}A)} = \Delta\mu_f{}^o{}_{GW(Route\text{-}B)} + \Delta\mu_f{}^o{}_{GW(Route\text{-}C)}$,

confirming the $\Delta\mu_f{}^o{}_{GW}$ as a state function.

Accordingly, a NP's $\mu_f{}^o{}_{GW}$ reduction in the hierarchical self-assembly bonding (see the **Extended Data Table S2a**) is quantifiable:

$\Delta\mu_f{}^o{}_{GW(2nm\text{-}NP\ in\ 8nm\text{-}NP)} = \Delta\mu_f{}^o{}_{GW(Route\text{-}A)}/64 = -3.71$ (keV) $= -(99.73\% \cdot \mu_f{}^o{}_{GW(2nm\text{-}NP)})$,

$\Delta\mu_f{}^o{}_{GW(2nm\text{-}NP\ in\ 4nm\text{-}NP)} = \Delta\mu_f{}^o{}_{GW(Route\text{-}B)}/64 = -3.49$ (keV) $= -(96.16\% \cdot \mu_f{}^o{}_{GW(2nm\text{-}NP)})$,

$\Delta\Delta\mu_f{}^o{}_{GW4nm\text{-}NP\ in\ 8nm\text{-}NP)} = \Delta\mu_f{}^o{}_{GW(Route\text{-}C)}/8 = -1.75$ (keV) $= -(94.09\% \cdot \mu_f{}^o{}_{GW(4nm\text{-}NP)})$.

These equations indicate smaller NPs' inter-bonding stronger than larger NPs', matching a stronger bonding between smaller atoms. Every NP's $\mu_f{}^o{}_{GW}$ loses nearly 100% in the bulk, since the $\tilde{\nu}^o{}_{GW(bulk)} = 0$ i.e. $\mu_f{}^o{}_{GW(bulk)} = 0$. This hierarchical bonding, driven by minimizing smaller particles higher $\mu_f{}^o{}_{GW}$ and generalizable to all self-assemblies[2-7], can complement with the electron-centered Chemical Bonding[8] Theory.

If assuming the $\Delta H_f{}^o{}_{GW} << \Delta\mu_f{}^o{}_{GW}$ in the self-assembly, then the $\Delta S_f{}^o{}_{GW(environment)} = -\Delta H_f{}^o{}_{GW}/T \approx 0$, and $\Delta S_f{}^o{}_{GW} \approx -\Delta\mu_f{}^o{}_{GW}/T > 0$. This helps predict quantitatively the $S_f{}^o{}_{GW}$ to complement with Boltzmann entropy-based thermodynamics.

If folding a 150-nm long 1D-polyethylene (PE) to an 8-nm NP (or backward unfolding), since the $d_{(ethylene)} \approx 0.390$ (nm)[9], the $\Delta\mu_f{}^o{}_{GW(Folding)} = \mu_f{}^o{}_{GW(0D\text{-}PE\text{-}NP)} - \mu_f{}^o{}_{GW(1D\text{-}PE\text{-}oligomer)} \approx (6/8)hc - (4/0.390)hc = -11.78$ (keV) = $-\Delta\mu_f{}^o{}_{GW(Unfolding)}$. This can help generalize a thinner 1D-NP's greater $\mu_f{}^o{}_{GW}$ for quantifying macromolecules inter-bonding (see the **Extended Data Tables S1 & S2a**).

For a mole of 8-nm NPs at T = 298 (^{o}K), the $\mu_{mf}{}^o{}_{GW(8nm\text{-}AuNP)} = 0.93$ (keV/NP) × (6.023 × 10^{23}) (NP/mole) × (1.60 × 10^{-19}) (kJ/keV) ≈ 8.96×10^4 (kJ/mole). Accordingly, the $S_{mf}{}^o{}_{GW(8nm\text{-}AuNP)} = -\mu_{mf}{}^o{}_{GW(8nm\text{-}AuNP)}/298 \approx -3.01 \times 10^5$ (J/K·mole).

Given the $\Delta\mu_f{}^o{}_{GW(bulk\ graphite)} = 0$ and $d_{(C\text{-}atom)} \approx 0.134$ (nm)[10], the $\mu_f{}^o{}_{GW}$ (see the **Extended Data Table S2b**) helps characterize large graphenes of different layers (~0.335 nm/layer) (**Fig. 1b**). The **Fig. 1b** can help quantify all thinner 2D-materials' higher $\mu_f{}^o{}_{GW}$ generally.

On an 8nm-NP, the $\mu_f{}^o{}_{GW}$ values of 2.0 nm-large surface vacancy defects (see the **Extended Data Table S2c**) are facet-defect's > edge-defect's > corner-defect's (**Fig. 1c**).

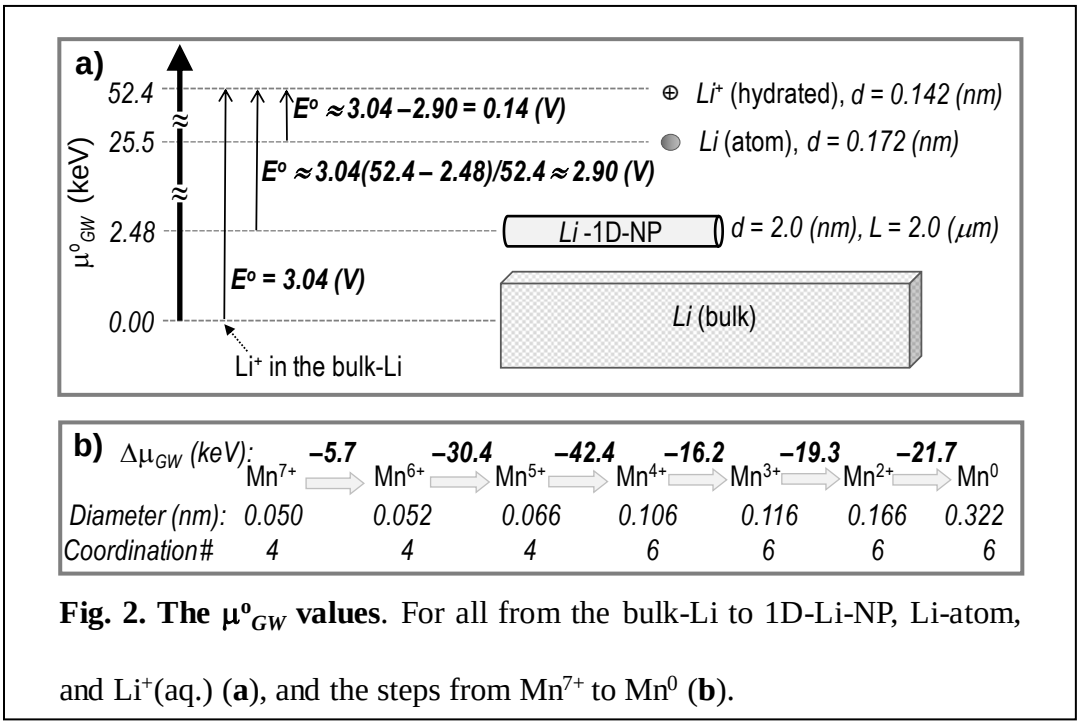
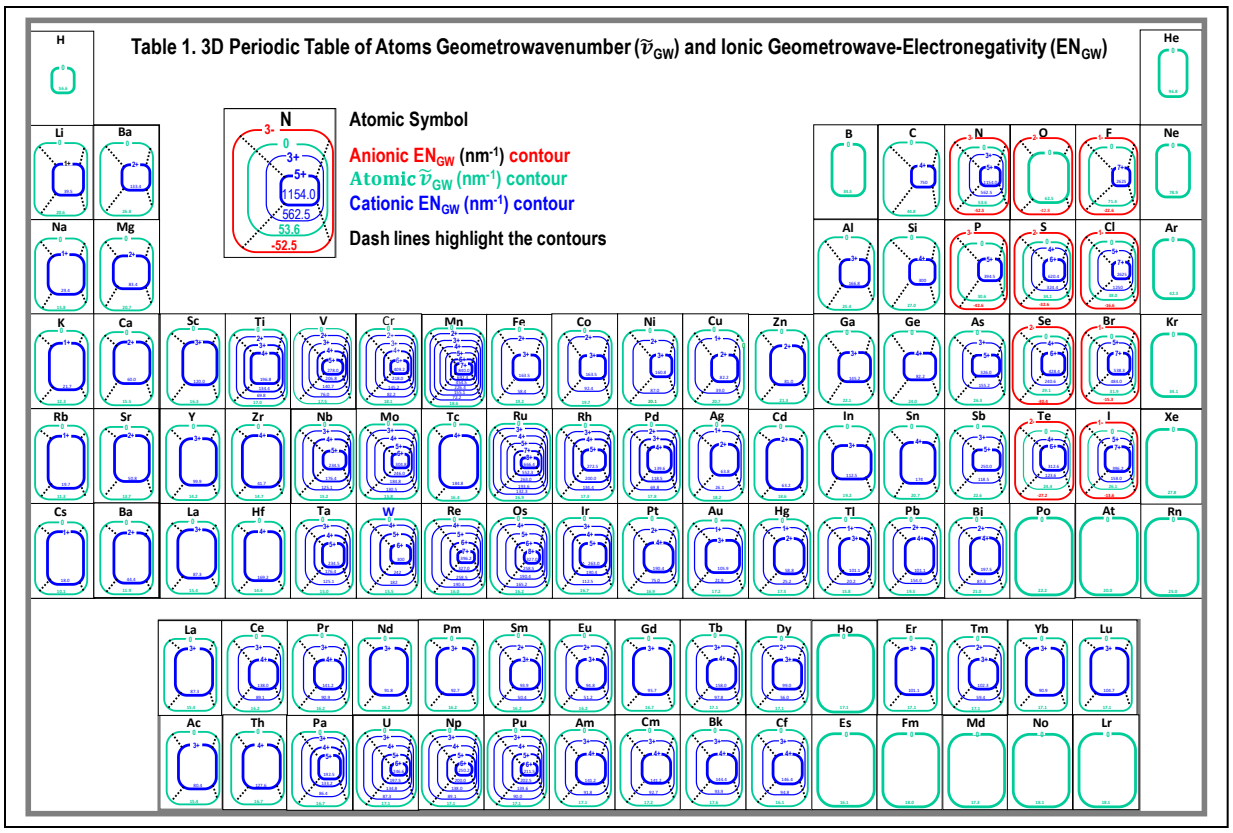


Fig. 2. The μ^{o}_{GW} values. For all from the bulk-Li to 1D-Li-NP, Li-atom, and Li^{+}(aq.) (**a**), and the steps from Mn^{7+} to Mn^{0} (**b**).

This helps generalize smaller defects' higher reactivity in the same order, to help study e.g. zeolites pores, proteins pockets and channels, and semiconductor surface vacancy defects.

On a bulk flat surface, the 2.0 nm-sized NP's spontaneous adsorption and "sintering" (see the **Extended Data Table S2d**) are each quantitatively characterizable (**Fig. 1d**). This can help quantitatively predict the $\mu_f{}^{o}{}_{QGD}$ in Surface Chemistry and Catalytic Chemistry, generally.

In Li-ion batteries[11-13], the electrochemically hard-to-measuring[14] reduction potential from a Li^{+}(aq.)[15] to a 2-μm-long, 2-nm-thick Li-1D-NP electrode (**Fig. 2a**) is estimable (see the **Extended Data Table S2e**), i.e. $E^{o}_{(cation\text{-}to\text{-}NP)} = E^{o}_{(cation\text{-}to\text{-}bulk)}\cdot(\mu_f{}^{o}{}_{GW(cation)} - \mu_f{}^{o}{}_{GW(NP)})/\mu_f{}^{o}{}_{GW(cation)} \approx -2.90$ (V). This can help quantify the $\Delta\mu_f{}^{o}{}_{GW}$ (**Fig. 2b**) between NPs, atoms, and ions (see the **Extended Data Tables S2f, S3 & S4**) for expanding the electrochemistry, redox chemistry, and Lewis acid-base chemistry, using ions' GW-electronegativity (EN_{GW}) = (6/d) × ±(ion's charge) (**Table 1**). Thus, the EN_{GW} = –(GW-electropositivity, or EP_{GW}),



for quantifying all ions' Lewis acidity (or basicity) in their compounding effectively using their EN_{GW} values.

The **Extended Data Table S1** supports a new nomenclature, "$\tilde{\nu}_{GW}$-(point-group)-composition", for characterizing NPs-bonded countless compounds. For example, an 1.5-nm PbS-0D-NP can be thus-labeled as (6/1.5)-(R_3)-PbS, a 10-nm 0D-ZnSe-NP as (6/10)-(R_3)-ZnSe, their 1:1 compound as (6/1.5)-(R_3)-PbS•(6/10)-(R_3)-ZnSe, the 1.5-nm PbS-0D-NPs' linear 100mer as 1D-{(6/1.5)-($D_{\infty d}$)-PbS}$_{100}$, and a 2-nm 0D-ZnO-NP's compound with a kinesin as (6/3)-(R_3)-ZnO-NP•kinesin, respectively.

In conclusion, the thermodynamics- and QM-complemented $\mu_f{}^o{}_{GW}$ has enabled consistently unifying and quantitatively predicting and comparing the particles' $\mu_f{}^o{}_{GW}$-quantized properties including their hierarchical self-assembly bonding, redox activity, folding–unfolding, acidity and/or basicity, surface defects reactivity, etc.

Atoms' and monoatomic ions' EN_{GW} values (see in **Extended Data Table S3**), potentially generalizable to the particles and oligomers, could help develop new basics for overhauling modern chemistry[16], which should be discussed separately.[17,18]

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EXTENDED DATA.

I. Extended Data Tables S1–S4.

II. References.

Title: **The geometrowave potential quantified and unified chemical properties**

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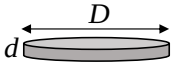
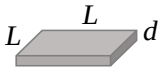
I. Extended Data Tables.

1). Extended Data[1] TableS1**:**

Table S1. Simple-Shape Particles' $\tilde{\nu}_{GW}$ and Point Group (Symmetry)

	Shape	Surface-Area (***SA***)	Volume (***V***)	$\tilde{\nu}_{GW}$ (= *SA*/*V*)	Point Group
0D		πd^2	$\pi d^3/6$	(6/*d*)*	R_3
1D		$4dL + 2d^2$	$d^2 L$	(4/*d* +2/*L*)** or (4/*d*)** *if* *d* << *L*	D_{4d}
		$\pi d^2/2 + \pi dL$	$\pi d^2 L/4$	(4/*d* + 2/*L*)** or (4/*d*)** *if* *d* << *L*	$D_{\infty d}$
2D		$\pi D^2/2 + d\pi D$	$d\pi D^2/4$	2/*d* + 4/*D*; or 2/*d* *if* *d* << *D*	$D_{\infty d}$
		$2(dL + dL + L^2)$	dL^2	2/*d* + 2/*L* + 2/*L*; or 2/*d* *if* *d* << *L*	D_{4d}
3D		$6d^2$	d^3	(6/*d*)*	O_h
		$2\times3^{1/2}d^2$	$2^{1/2}d^3/3$	$3\times6^{1/2}/d$	O_h
		$1.732d^2$	$0.118d^3$	$14.678/d$	T_d

*The spherical and cubic particles share the same $\tilde{\nu}_{GW}$ formula;
**The two 1D-particles share the same $\tilde{\nu}_{GW}$ formula.

2). Extended Data Table S2:

Table S2. Calculations of the μ^{o}_{GW}

a) $\mu^{o}_{GW(\text{Au-atom})} = (17.2)hc = 21.33$ (keV),
$\mu^{o}_{GW(\text{2nm-AuNP})} = (6/2)hc = 3.72$ (keV),
$\mu^{o}_{GW(\text{4nm-AuNP})} = (6/4)hc = 1.86$ (keV),
$\mu^{o}_{GW(\text{8nm-AuNP})} = (6/8)hc = 0.93$ (keV).

b) $\mu^{o}_{GW(\text{C-atom})} = (44.8)hc = 55.55$ (keV),
$\mu^{o}_{GW(\text{1-layer graphene})} = hc\{2/(1 \times 0.335)\} = 7.40$,
$\mu^{o}_{GW(\text{2-layer graphene})} = hc\{2/(2 \times 0.335)\} = 3.70$ (keV),
$\mu^{o}_{GW(\text{4-layer graphene})} = hc\{2/(4 \times 0.335)\} = 1.85$ (keV).

c) $\mu^{o}_{GW(\text{facet-defect})} = hc\{(SA/V)_{(\text{2-nm defect on 8-nm NP})}\} = hc\{(4\times2^2+6\times8^2)/(8^3-2^3)\} = hc\{(4\times2^2+384)/504\} = 0.98$ (keV),
$\mu^{o}_{GW(\text{edge-defect})} = hc\{(2\times2^2+384)/504\} = 0.96$ (keV),
$\mu^{o}_{GW(\text{corner-defect})} = hc\{384/504 - 17.2\} = 0.94$ (keV).

d) $\mu^{o}_{GW(\text{2nm-NP-on-large flat surface})} = hc\{(5 \times 2^2)/8\} = 3.10$ (keV),
$\mu^{o}_{GW(\text{hemisphere-on-large flat surface})} = hc\{(\pi d^2)/(\pi d^3/6)\} \approx hc(6/d) = hc(6/3.13) = 2.38$ (keV).

e) $\mu^{o}_{GW(\text{Li (I) hydrated cation})} = hc(SA/V)_{\text{hydrated-Li-(I)-cation}} = hc(6/0.142) = 52.4$ (keV),
$\mu^{o}_{GW(\text{Li atom})} = hc(SA/V)_{\text{Li-atom}} = hc(20.6) = 25.5$ (keV),
$\mu^{o}_{GW(\text{Li-1D-NP})} \approx hc(4/d) = hc(4/2) = 2.48$ (keV).

f) $\mu^{o}_{GW(\text{Mn(VII)})} = hc(6/0.050) = 148.8$ (keV),
$\mu^{o}_{GW(\text{Mn(VI)})} = hc(6/0.052) = 143.1$ (keV),
$\mu^{o}_{GW(\text{Mn(V)})} = hc(6/0.066) = 112.7$ (keV),
$\mu^{o}_{GW(\text{Mn(IV)})} = hc(6/0.106) = 70.3$ (keV),
$\mu^{o}_{GW(\text{Mn(III)})} = hc(6/0.116) = 64.1$ (keV),
$\mu^{o}_{GW(\text{Mn(II)})} = hc(6/0.166) = 44.8$ (keV),
$\mu^{o}_{GW(\text{Mn(0)})} = hc(6/0.322) = 23.1$ (keV)

3. Extended Data[1] Table S3:

Table S3. Periodicities of Atoms $\tilde{\nu}_{GW}$

H 0.106 **56.6** *2.20*																	**He** 0.062 **96.8**
Li 0.234 **20.6** *0.98*	**Be** 0.224 **26.8** *1.57*											**B** 0.174 **34.5** *2.04*	**C** 0.134 **44.8** *2.55*	**N** 0.112 **53.6** *3.04*	**O** 0.096 **62.5** *3.44*	**F** 0.084 **71.4** *3.98*	**Ne** 0.076 **78.9**
Na 0.380 **15.8** *0.93*	**Mg** 0.290 **20.7** *1.31*											**Al** 0.236 **25.4** *1.61*	**Si** 0.222 **27.0** *1.90*	**P** 0.196 **30.6** *2.19*	**S** 0.176 **34.1** *2.58*	**Cl** 0.158 **38.0** *3.16*	**Ar** 0.142 **42.3**
K 0.486 **12.3** *0.82*	**Ca** 0.388 **15.5** *1.00*	**Sc** 0.368 **16.3** *1.36*	**Ti** 0.352 **17.0** *1.54*	**V** 0.342 **17.5** *1.63*	**Cr** 0.332 **18.1** *1.66*	**Mn** 0.322 **18.6** *1.55*	**Fe** 0.312 **19.2** *1.83*	**Co** 0.304 **19.7** *1.88*	**Ni** 0.298 **20.1** *1.91*	**Cu** 0.290 **20.7** *1.90*	**Zn** 0.282 **21.3** *1.65*	**Ga** 0.272 **22.1** *1.81*	**Ge** 0.250 **24.0** *2.01*	**As** 0.228 **26.3** *2.18*	**Se** 0.206 **29.1** *2.55*	**Br** 0.188 **31.9** *2.96*	**Kr** 0.176 **34.1**
Rb 0.530 **11.3** *0.82*	**Sr** 0.438 **13.7** *0.95*	**Y** 0.424 **14.2** *1.22*	**Zr** 0.412 **14.7** *1.33*	**Nb** 0.396 **15.2** *1.6*	**Mo** 0.380 **15.8** *2.16*	**Tc** 0.366 **16.4** *2.10*	**Ru** 0.356 **16.9** *2.2*	**Rh** 0.346 **17.3** *2.28*	**Pd** 0.338 **17.8** *2.20*	**Ag** 0.330 **18.2** *1.93*	**Cd** 0.322 **18.6** *1.69*	**In** 0.312 **19.2** *1.78*	**Sn** 0.290 **20.7** *1.96*	**Sb** 0.266 **22.6** *2.05*	**Te** 0.246 **24.4** *2.1*	**I** 0.230 **26.1** *2.66*	**Xe** 0.216 **27.8** *2.60*
Cs 0.596 **10.1** *0.79*	**Ba** 0.506 **11.9** *0.89*	**La** 0.390 **15.4** *1.10*	**Hf** 0.416 **14.4** *1.3*	**Ta** 0.400 **15.0** *1.5*	**W** 0.386 **15.5** *1.7*	**Re** 0.376 **16.0** *1.9*	**Os** 0.370 **16.2** *2.2*	**Ir** 0.360 **16.7** *2.2*	**Pt** 0.354 **16.9** *2.2*	**Au** 0.348 **17.2** *2.4*	**Hg** 0.342 **17.5** *1.9*	**Tl** 0.312 **15.8** *1.8*	**Pb** 0.308 **19.5** *1.8*	**Bi** 0.286 **21.0** *1.9*	**Po** 0.270 **22.2** *2.0*	**At** 0.300 **20.0** *2.2*	**Rn** 0.240 **25.0**
		La 0.390 **15.4** *1.10*	**Ce** 0.370 **16.2** *1.12*	**Pr** 0.370 **16.2** *1.13*	**Nd** 0.370 **16.2** *1.1*	**Pm** 0.370 **16.2**	**Sm** 0.370 **16.2** *1.17*	**Eu** 0.370 **16.2**	**Gd** 0.360 **16.7** *1.20*	**Tb** 0.350 **17.1**	**Dy** 0.350 **17.1** *1.22*	**Ho** 0.350 **17.1** *1.23*	**Er** 0.350 **17.1** *1.24*	**Tm** 0.350 **17.1** *1.25*	**Yb** 0.350 **17.1**	**Lu** 0.350 **17.1** *1.0*	
		Ac 0.390 **15.4** *1.1*	**Th** 0.360 **16.7** *1.3*	**Pa** 0.360 **16.7** *1.5*	**U** 0.350 **17.1** *1.7*	**Np** 0.350 **17.1** *1.3*	**Pu** 0.350 **17.1** *1.3*	**Am** 0.350 **17.1**	**Cm** 0.348 **17.2**	**Bk** 0.340 **17.6**	**Cf** 0.372 **16.1**	**Es** 0.372 **16.1**	**Fm** 0.334 **18.0**	**Md** 0.346 **17.3**	**No** 0.332 **18.1**	**Lr** 0.322 **18.1**	

La
0.390
15.4
1.10

Atomic Symbol
Atomic diameter* {unit: (nm)}
$\tilde{\nu}_{GW}$ **(unit: nm^{-1})**
*Pauling's EN****

*Atomic diameters data source:
https://en.wikipedia.org/wiki/Atomic_radii_of_the_elements_(data_page) (Jan-8-2019).

**Pauling's EN data source:
Lide, D. R. *CRC Handbook of Chem. and Phys.* (CRC Press, Boca Raton, FL, 2000).

4). Extended Data[2,3] Table S4:

Table S4. Monoatomic ions' EN_{GW} values

ions	C.N.*	r (nm)	6/d (nm^{-1})	EN_{GW} (nm^{-1})**
F^{-}	6	0.133	22.6	-22.6
Cl^{-}	6	0.181	16.6	-16.6
Br^{-}	6	0.196	15.3	-15.3
I^{-}	6	0.220	13.6	-13.6
OH^{-}	4	0.135	22.2	-22.2
	6	0.137	21.9	-21.9
O^{-2}	2	0.121	24.8	-49.6
	6	0.140	21.4	-42.8
	8	0.142	21.1	-42.2
S^{-2}	6	0.184	16.3	-32.6
Se^{-2}	6	0.198	15.2	-30.4
Te^{-2}	6	0.221	13.6	-27.2
N^{-3}	6	0.171	17.5	-52.5
P^{-3}	6	0.212	14.2	-42.6
Ac^{+3}	6	0.112	26.8	80.4
Ag^{+1}	4	0.100	30.0	30.0
	6	0.115	26.1	26.1
	8	0.128	23.4	23.4
Ag^{+2}	4	0.079	38.0	76.0
	6	0.094	31.9	63.8
Al^{+3}	4	0.039	76.9	230.7
	5	0.048	62.5	187.5
	6	0.054	55.6	166.8
Am^{+3}	6	0.098	30.6	91.8
	8	0.109	27.5	82.5
Am^{+4}	6	0.085	35.3	141.2
	8	0.095	31.6	126.4
As^{+3}	6	0.058	51.7	155.2
As^{+5}	4	0.034	88.2	441
	6	0.046	65.2	326
Au^{+1}	6	0.137	21.9	21.9
Au^{+3}	4	0.064	46.9	140.7
	6	0.085	35.3	105.9
Ba^{+2}	6	0.135	22.2	44.4
	8	0.142	21.1	42.2
	12	0.161	18.6	37.2
Be^{+2}	4	0.027	111.1	222.2
	6	0.045	66.7	133.4
Bi^{+3}	5	0.096	31.3	93.9
	6	0.103	29.1	87.3
	8	0.117	25.6	76.8
Bi^{+5}	6	0.076	39.5	197.5
Bk^{+3}	6	0.096	31.3	93.9
BK^{+4}	6	0.083	36.1	144.4
	8	0.093	32.3	129.2
Br^{+5}	3	0.031	96.8	484
Br^{+7}	4	0.025	120	840
	6	0.039	76.9	538.3
C^{+4}	4	0.015	200	800
	6	0.016	187.5	750
Ca^{+2}	6	0.100	30.0	60.0
	8	0.112	26.8	53.6
	10	0.123	24.4	48.8
	12	0.134	22.4	44.8
Cd^{+2}	4	0.078	38.5	77.0
	6	0.095	31.6	63.2
	8	0.110	27.3	54.6
	12	0.131	22.9	45.8
Ce^{+3}	6	0.101	29.7	89.1
	8	0.114	26.3	78.9
	10	0.125	24.0	72.0
	12	0.134	22.4	67.2
Ce^{+4}	6	0.087	34.5	138
	8	0.097	30.9	123.6
	10	0.107	28.0	112
	12	0.114	26.3	105.2
Cf^{+3}	6	0.095	31.6	94.8
Cf^{+4}	6	0.082	36.6	146.4
	8	0.092	32.6	130.4
Cl^{+5}	3	0.012	250	1250
Cl^{+7}	4	0.008	375	2625
Cm^{+3}	6	0.097	30.9	92.7
Cm^{+4}	6	0.085	35.3	141.2
	8	0.095	31.6	126.4
Co^{+2}	4	0.056	53.6	107.2
	6	0.065	46.2	92.4
	8	0.090	33.3	66.6
Co^{+3}	6	0.055	54.5	163.5
Cr^{+2}	6	0.073	41.1	82.2
Cr^{+3}	6	0.062	48.4	145.2
Cr^{+4}	4	0.041	73.2	292.8
	6	0.055	54.5	218
Cr^{+6}	4	0.026	115.4	692.4
	6	0.044	68.2	409.2
Cs^{+1}	6	0.167	18.0	18.0
	8	0.174	17.2	17.2
	10	0.181	16.6	16.6
	12	0.188	16.0	16.0
Cu^{+1}	2	0.046	65.2	65.2
	4	0.060	50.0	50.0
	6	0.077	39.0	39.0
Cu^{+2}	4	0.057	52.6	105.2
	6	0.073	41.1	82.2
Dy^{+2}	6	0.107	28.0	56.0
	8	0.119	25.2	50.4
Dy^{+3}	6	0.091	33.0	99.0
	8	0.103	29.1	87.3
Er^{+3}	6	0.089	33.7	101.1
	8	0.100	30.0	90.0
Eu^{+2}	6	0.117	25.6	51.2
	8	0.125	24.0	48.0
	10	0.135	22.2	44.4
Eu^{+3}	6	0.095	31.6	94.8
	8	0.107	21.1	63.3
F^{+7}	6	0.008	375	2625
Fe^{+2}	4	0.063	47.6	95.2
	6	0.061	49.2	58.4
	8	0.092	32.6	65.2
Fe^{+3}	4	0.049	61.2	183.6
	6	0.055	54.5	163.5
	8	0.078	38.5	115.5
Ga^{+3}	4	0.047	63.8	191.4
	6	0.062	48.4	145.2
Gd^{+3}	6	0.094	31.9	95.7
	8	0.105	28.6	85.8
Ge^{+2}	6	0.073	41.1	82.2
Ge^{+4}	4	0.039	76.9	307.6
	6	0.053	56.6	226.4
Hf^{+4}	4	0.058	51.7	206.8
	6	0.071	42.3	169.2
	8	0.083	36.1	144.4
Hg^{+1}	6	0.119	25.2	25.2
Hg^{+2}	2	0.069	43.5	87.0
	4	0.096	31.3	62.6
	6	0.102	29.4	58.8
	8	0.114	26.3	52.6
I^{+5}	3	0.044	68.2	341
	6	0.095	31.6	158
I^{+7}	4	0.042	71.4	499.8
	6	0.053	56.6	396.2
In^{+3}	4	0.062	48.4	145.2
	6	0.080	37.5	112.5
Ir^{+3}	6	0.068	44.1	132.3
Ir^{+4}	6	0.063	47.6	190.4
Ir^{+5}	6	0.057	52.6	263
K^{+1}	4	0.137	21.9	21.9
	6	0.138	21.7	21.7
	8	0.151	19.9	19.9
	12	0.164	18.3	18.3
La^{+3}	6	0.103	29.1	87.3
	8	0.116	25.9	77.7
	10	0.127	23.6	708
	12	0.136	22.1	66.3
Li^{+1}	4	0.059	50.8	50.8
	6	0.076	39.5	39.5
	8	0.092	32.6	32.6
Lu^{+3}	6	0.086	34.9	104.7
	8	0.097	30.9	92.7
Mg^{+2}	4	0.057	52.6	105.2
	6	0.072	41.7	83.4
	8	0.089	33.7	67.4
Mn^{+2}	4	0.066	45.5	91.0
	6	0.083	36.1	72.2
	8	0.096	31.3	62.6
Mn^{+3}	6	0.058	51.7	155.1
Mn^{+4}	4	0.039	76.9	307.6
	6	0.053	56.6	226.4
Mn^{+5}	4	0.033	90.9	454.5
Mn^{+6}	4	0.026	115.4	692.4
Mn^{+7}	4	0.025	120	840
Mo^{+3}	6	0.069	43.5	130.5
Mo^{+4}	6	0.065	46.2	184.8
Mo^{+5}	4	0.046	65.2	326
	6	0.061	49.2	246
Mo^{+6}	4	0.041	73.2	439.2
	6	0.059	50.8	304.8
	7	0.073	41.1	246.6
N^{+3}	6	0.016	187.5	562.5
N^{+5}	6	0.013	230.8	1154
Na^{+1}	4	0.099	30.3	30.3
	6	0.102	29.4	29.4
	8	0.118	25.4	25.4
	9	0.124	24.2	24.2
	12	0.13	23.1	23.1
Nb^{+3}	6	0.072	41.7	125.1
	8	0.079	38.0	114

*CN: Coordination Number, and CN = 6 for most cases in the **Table 1**

**EN_{GW} unit: (nm^{-1})

4). Extended Data Table S4 (continued):

Ions	C.N.	r (nm)	6/d (nm^{-1})	EN_{GW}	Ions	C.N.	r (nm)	6/d (nm^{-1})	EN_{GW}	Ions	C.N.	r (nm)	6/d (nm^{-1})	EN_{GW}	Ions	C.N.	r (nm)	6/d (nm^{-1})	EN_{GW}
Nb^{+4}	6	0.068	44.1	177.6	Pr^{+4}	6	0.085	35.3	141.2	Sm^{+2}	6	0.119	25.2	50.4	Tm^{+2}	6	0.101	29.7	59.4
Nb^{+5}	4	0.048	62.5	312.5		8	0.096	31.3	125.2		8	0.127	23.6	47.2		7	0.109	27.5	55.0
	6	0.064	46.9	234.5	Pt^{+2}	4	0.060	50.0	100	Sm^{+3}	6	0.096	31.3	93.9	Tm^{+3}	6	0.088	34.1	102.3
	8	0.074	40.5	202.5		6	0.080	37.5	75.0		8	0.108	27.8	83.4		8	0.099	30.3	90.9
Nd^{+3}	6	0.098	30.6	91.8	Pt^{+4}	6	0.063	47.6	190.4		12	0.124	24.2	72.6	U^{+3}	6	0.103	29.1	87.3
	8	0.112	26.8	80.4	Pu^{+3}	6	0.100	30.0	90.0	Sn^{+4}	4	0.055	54.5	218	U^{+4}	6	0.089	33.7	134.8
	9	0.116	25.9	77.7	Pu^{+4}	6	0.086	34.9	139.6		6	0.069	43.5	174		8	0.100	30.0	120
	12	0.127	23.6	70.8	Pu^{+5}	6	0.074	40.5	202.5		8	0.081	37.0	148		12	0.117	25.6	102.4
Ni^{+2}	4	0.049	61.2	122.4	Pu^{+6}	6	0.071	42.3	211.5	Sr^{+2}	6	0.118	25.4	50.8	U^{+5}	6	0.076	39.5	197.5
	6	0.069	43.5	87.0	Rb^{+1}	6	0.152	19.7	19.7		8	0.126	23.8	47.6	U^{+6}	2	0.045	66.7	400.2
Ni^{+3}	6	0.056	53.6	160.8		8	0.161	18.6	18.6		10	0.136	22.1	44.2		4	0.052	57.7	346.2
Np^{+3}	6	0.101	29.7	89.1		10	0.166	18.1	18.1		12	0.144	20.8	41.6		6	0.073	41.1	246.6
Np^{+4}	6	0.087	34.5	138		12	0.172	17.4	17.4	Ta^{+3}	6	0.072	41.7	125.1		8	0.086	34.9	209.4
Np^{+5}	6	0.075	40.0	200	Re^{+4}	6	0.063	47.6	190.4	Ta^{+4}	6	0.068	44.1	176.4	V^{+2}	6	0.079	38.0	76.0
Np^{+6}	6	0.072	41.7	250.2	Re^{+5}	6	0.058	51.7	258.5	Ta^{+5}	6	0.064	46.9	234.5	V^{+3}	6	0.064	46.9	140.7
Os^{+4}	6	0.063	47.6	190.4	Re^{+6}	6	0.055	54.5	327	Tb^{+3}	6	0.092	32.6	97.8	V^{+4}	5	0.053	56.6	226.4
Os^{+5}	6	0.058	51.7	258.5	Re^{+7}	4	0.038	78.9	552.3		8	0.104	28.8	86.4		6	0.058	51.7	206.8
Os^{+6}	6	0.055	54.5	327		6	0.053	56.6	396.2	Tb^{+4}	6	0.076	39.5	158		8	0.072	41.7	166.8
Os^{+8}	6	0.039	76.9	615.2	Rh^{+3}	6	0.067	44.8	134.4		8	0.088	34.1	136.4	V^{+5}	4	0.036	83.3	416.5
P^{+5}	4	0.017	176.5	882.5	Rh^{+4}	6	0.060	50.0	200	Tc^{+4}	6	0.065	46.2	184.8		5	0.046	65.2	326
	6	0.038	78.9	394.5	Rh^{+5}	6	0.055	54.5	272.5	Te^{+4}	4	0.066	45.5	182		6	0.054	55.6	278
Pa^{+3}	6	0.104	28.8	86.4	Ru^{+3}	6	0.068	44.1	132.3		6	0.097	30.9	123.6	W^{+4}	6	0.066	45.5	182
Pa^{+4}	6	0.090	33.3	133.2	Ru^{+4}	6	0.062	48.4	193.6	Te^{+6}	4	0.043	69.8	418.8	W^{+5}	6	0.062	48.4	242
Pa^{+5}	6	0.078	38.5	192.5	Ru^{+5}	6	0.057	52.6	263		6	0.056	53.6	321.6	W^{+6}	4	0.042	71.4	428.4
Pb^{+2}	6	0.119	25.2	50.4	Ru^{+7}	4	0.038	78.9	552.3	Th^{+4}	6	0.094	31.9	127.6		5	0.051	58.8	352.8
	8	0.129	23.3	46.6	Ru^{+8}	4	0.036	83.3	670.4		8	0.105	28.6	114.4		6	0.060	50.0	300
	10	0.140	21.4	42.8	S^{+4}	6	0.037	81.1	324.4		10	0.113	26.5	106	Y^{+3}	6	0.090	33.3	99.9
	12	0.149	20.1	40.2	S^{+6}	4	0.012	250	1500		12	0.121	24.8	99.2		8	0.102	29.4	88.2
Pb^{+4}	4	0.065	46.2	184.8		6	0.029	103.4	620.4	Ti^{+2}	6	0.086	34.9	69.8		9	0.108	27.8	83.4
	6	0.078	38.5	154	Sb^{+3}	4	0.076	39.5	118.5	Ti^{+3}	6	0.067	44.8	134.4	Yb^{+2}	6	0.102	29.4	58.8
	8	0.094	31.9	127.6		6	0.076	39.5	118.5	Ti^{+4}	4	0.042	71.4	285.6		8	0.114	26.3	52.6
Pd^{+2}	4	0.064	46.9	93.8	Sb^{+5}	6	0.060	50.0	250		6	0.061	49.2	196.8	Yb^{+3}	8	0.099	30.3	90.9
	6	0.086	34.9	69.8	Sc^{+3}	6	0.075	40.0	120		8	0.074	40.5	162		9	0.104	28.8	86.4
Pd^{+3}	6	0.076	39.5	118.5		8	0.087	34.5	103.5	Tl^{+1}	6	0.150	20.0	20.2	Zn^{+2}	4	0.060	50.0	100
Pd^{+4}	6	0.062	48.4	193.6	Se^{+4}	6	0.050	60.0	240		8	0.159	18.9	18.9		6	0.074	40.5	81.0
Pm^{+3}	6	0.097	30.9	92.7	Se^{+6}	4	0.028	107.1	642.6		12	0.170	17.6	17.6		8	0.090	33.3	66.6
	8	0.109	27.5	82.5		6	0.042	71.4	428.4	Tl^{+3}	4	0.075	40.0	120	Zr^{+4}	4	0.059	50.8	203.2
Pr^{+3}	6	0.099	30.3	90.9	Si^{+4}	4	0.026	115.4	461.6		6	0.089	33.7	101.1		6	0.072	41.7	166.8
	8	0.113	26.5	79.5		6	0.040	75.0	300		8	0.098	30.6	91.8		8	0.084	35.7	142.8
																9	0.089	33.7	134.8

II. References:

[1] Tian, Z. R. Nanoparticles' and Atoms' Geometry-Wave Potential Quantified and Unified Properties. ChemRxiv. Preprint (2019). https://doi.org/10.26434/chemrxiv.9759551.v3.

[2] Ionic radii, Lide, D. R. *CRC Handbook of Chem. and Phys.* (CRC Press, Boca Raton, FL, 2000). http://diyhpl.us/~nmz787/mems/unorganized/CRC%20Handbook%20of%20Chemistry%20and%20Physics%2085th%20edition.pdf.

[3] For the N^{-3} and P^{3-} radii: https://www.chemguide.co.uk/atoms/properties/atradius.html.