Title: **The geometrowave potential quantified and unified properties in general chemistry**

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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,

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

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

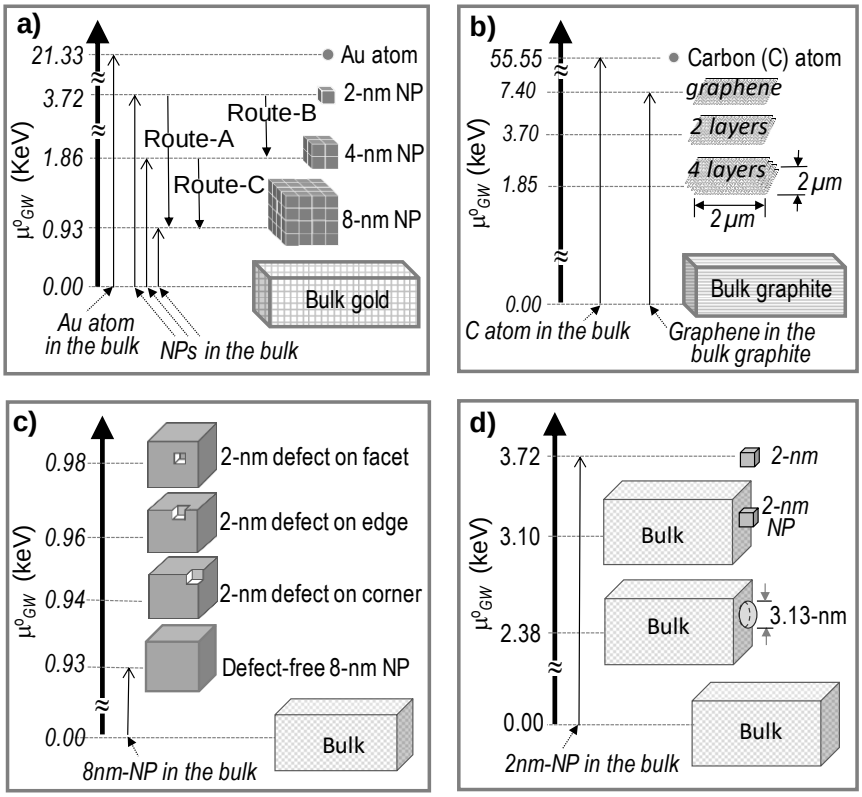


Fig. 1. The μ^o_{GW} values. For the Au-NPs self-assembly (**a**), the graphene-layers (**b**), a 2-nm surface-defects on an 8-nm NP (**c**), and a 2-nm NP's adsorption and sintering on a large surface (**d**).

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

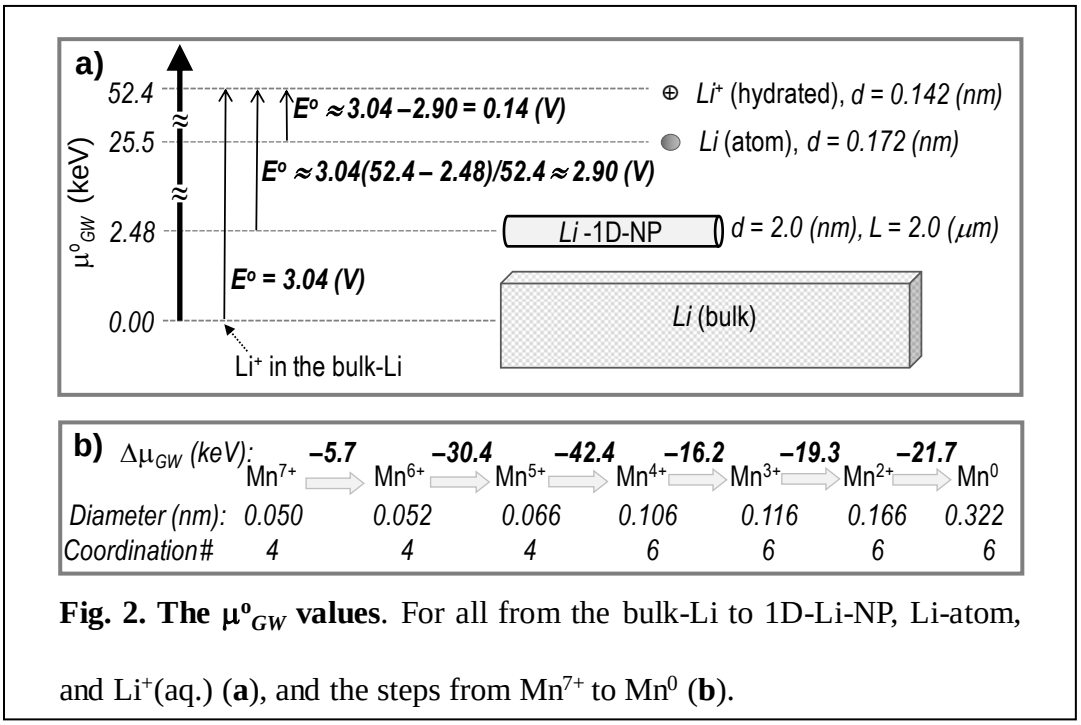
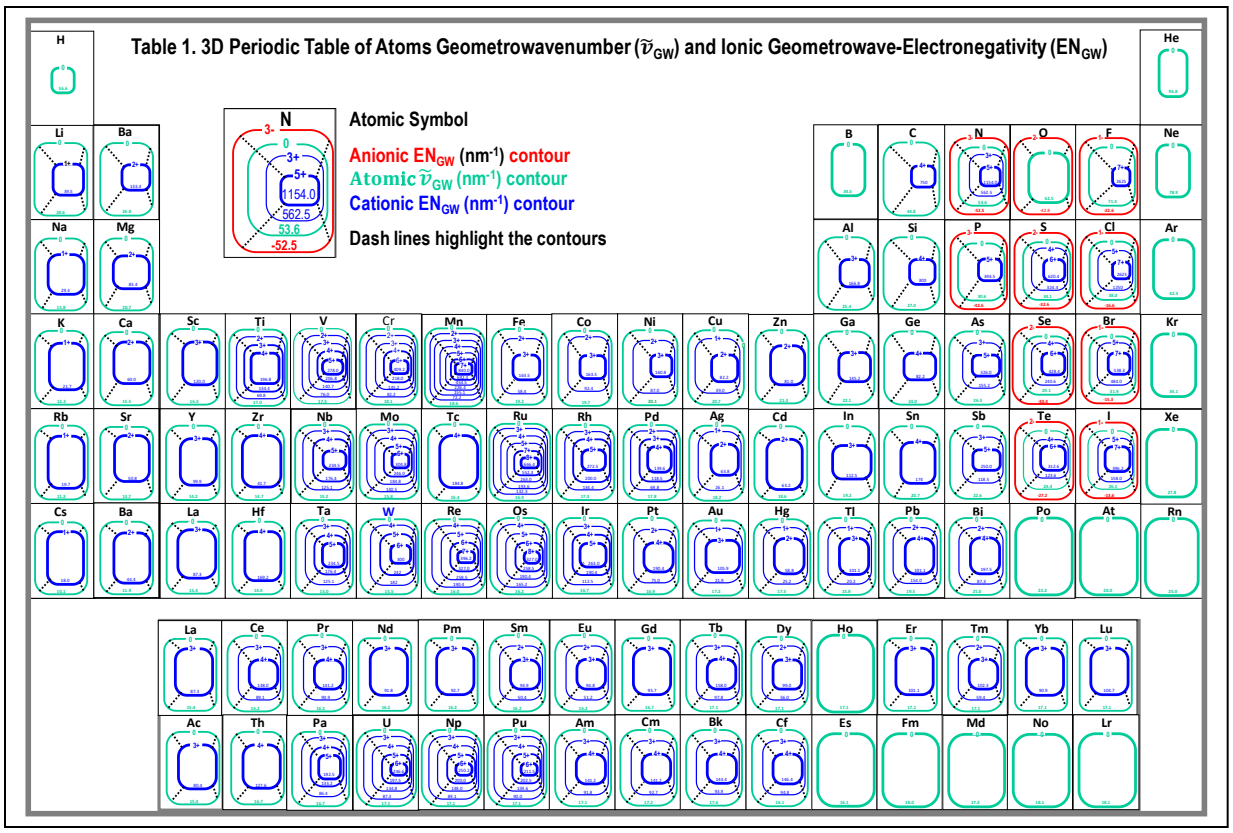


Fig. 2. The μ^{o}_{GW} values. For all from the bulk-Li to 1D-Li-NP, Li-atom, and Li^{+}(aq.) (**a**), and the steps from Mn^{7+} to Mn^{0} (**b**).

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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Acknowledgement: The author thanks Drs. H. W. Kroto, J. T. Yates, Z. L. Wang, P. Pulay, C. D. Heyes, and H. C. Tian for fruitful discussions.

EXTENDED DATA.

I. Extended Data Tables S1–S4.

II. References.

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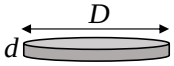
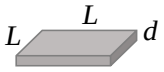
I. Extended Data Tables.

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.