# CHEM 548: MATERIALS CHEMISTRY

## LECTURE 11: IONIC BONDING

Wed 09/30/2026 · Meeting 11

**Reading:** Woodward, Karen, Evans, and Vogt, *Solid State Materials Chemistry*
Ch. 5, §5.1

# IONIC BONDING

By the end of this lecture, you should be able to:

| | |
|---|---|
| **Bonding → properties** | explain why chemical bonding connects **structure** to **properties** of materials. |
| **Ionic bonding** | define it as electrostatic interactions between **point charges**. |
| **Coulomb's law** | apply it to estimate **attractive vs. repulsive** interactions between ions. |
| **Madelung constant** | describe how **coordination number** and **structure type** affect it. |
| **Structure dependence** | explain what the Madelung constant represents and why it differs for **NaCl, CsCl, ZnS**, etc. |
| **Lattice energy** | define it, and distinguish lattice **energy** from lattice **enthalpy**. |
| **Born–Mayer equation** | use it to estimate lattice energies, recognizing the role of **repulsive terms**. |

# COULOMB INTERACTION

$$U_C = \frac{(z_1 e)\cdot(z_2 e)}{4\pi\varepsilon_0 d}$$

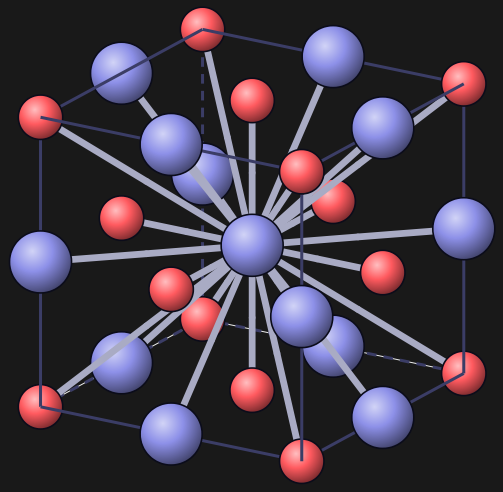
— magnitude of the charges

— distance between charges

| | |
|---|---|
| **Cation–Anion** | Interaction – **Attractive** |
| **Anion–Anion** | Interaction – **Repulsive** |
| **Cation–Cation** | Interaction – **Repulsive** |

Per *Solid State Materials Chemistry*, §5.1.1, Eq. (5.1).

# MADELUNG SUM



| shell | 6 $Na^+$ at d | 12 $Cl^-$ at $\sqrt{2}$ d | 8 $Na^+$ at $\sqrt{3}$ d |
|---|---|---|---|
| running sum | +6/√1 → 6.000 | −12/√2 → −2.485 | +8/√3 → 2.134 |

$$V_C = \frac{(z_1 e)\cdot(z_2 e)}{4\pi\varepsilon_0 d}\left(\frac{6}{\sqrt{1}} - \frac{12}{\sqrt{2}} + \frac{8}{\sqrt{3}} - \frac{6}{\sqrt{4}} + \frac{24}{\sqrt{5}} - \frac{24}{\sqrt{6}} - \frac{12}{\sqrt{8}} \cdots\right)$$

If the shells are chosen in the right way (charge neutral shells) this sum converges to a value of $1.7476$. This is the Madelung constant, $A$ for the NaCl structure type

Per *Solid State Materials Chemistry*, §5.1.1, Eq. (5.2).

# MADELUNG CONSTANTS AND STRUCTURE TYPE

| 1:1 compounds, MX | | | 1:2 compounds, $MX_2$ | | |
|---|---|---|---|---|---|
| **Structure Type** | **Coordination** | ***A*** | **Structure Type** | **Coordination** | ***A*** |
| Cesium chloride | $Cs^{[8]}Cl^{[8]}$ | 1.763 | Fluorite | $Ca^{[8]}F_2^{[4]}$ | 2.519 |
| Rock salt | $Na^{[6]}Cl^{[6]}$ | 1.748 | Rutile 3D network | $Ti^{[6]}O_2^{[3]}$ | 2.408 |
| Wurtzite | $Zn^{[4]}S^{[4]}$ | 1.641 | Cadmium chloride layered | $Cd^{[6]}Cl_2^{[3]}$ | 2.244 |
| Zinc blende | $Zn^{[4]}S^{[4]}$ | 1.638 | Cadmium iodide layered | $Cd^{[6]}I_2^{[3]}$ | 2.192 |

Electrostatic interactions favor symmetric structures with close packing of anions and cations and high coordination numbers.

Values per *Solid State Materials Chemistry*, §5.1.1, Table 5.1.

# LATTICE ENERGY

## Lattice Energy ($U_{\mathrm{L}}$):

The amount of energy that is released when one mole of a crystal is formed from its constituent ions at infinite separation in the gas phase at $T$ = 0 K

$$a\,\mathrm{M}^{y+}(g) \;+\; b\,\mathrm{X}^{z-}(g) \rightarrow \mathrm{M}_a\mathrm{X}_b(s)$$

Lattice energy is exothermic

Lattice energy is approximately equal to lattice enthalpy, $U_{\mathrm{L}} = H_{\mathrm{L}}$

Per *Solid State Materials Chemistry*, §5.1.2, Eq. (5.4).

# LATTICE ENERGY

$$U_{\mathrm{C}} = \frac{z_1 z_2 e^2 N_{\mathrm{A}}}{4\pi\varepsilon_0 d} A \qquad U_{\mathrm{r}} = B e^{-\frac{d}{\rho}}$$

distance between ions

0.345 Å

The lattice energy in the absence of repulsive forces

Repulsive interactions, caused by overlap of core orbitals

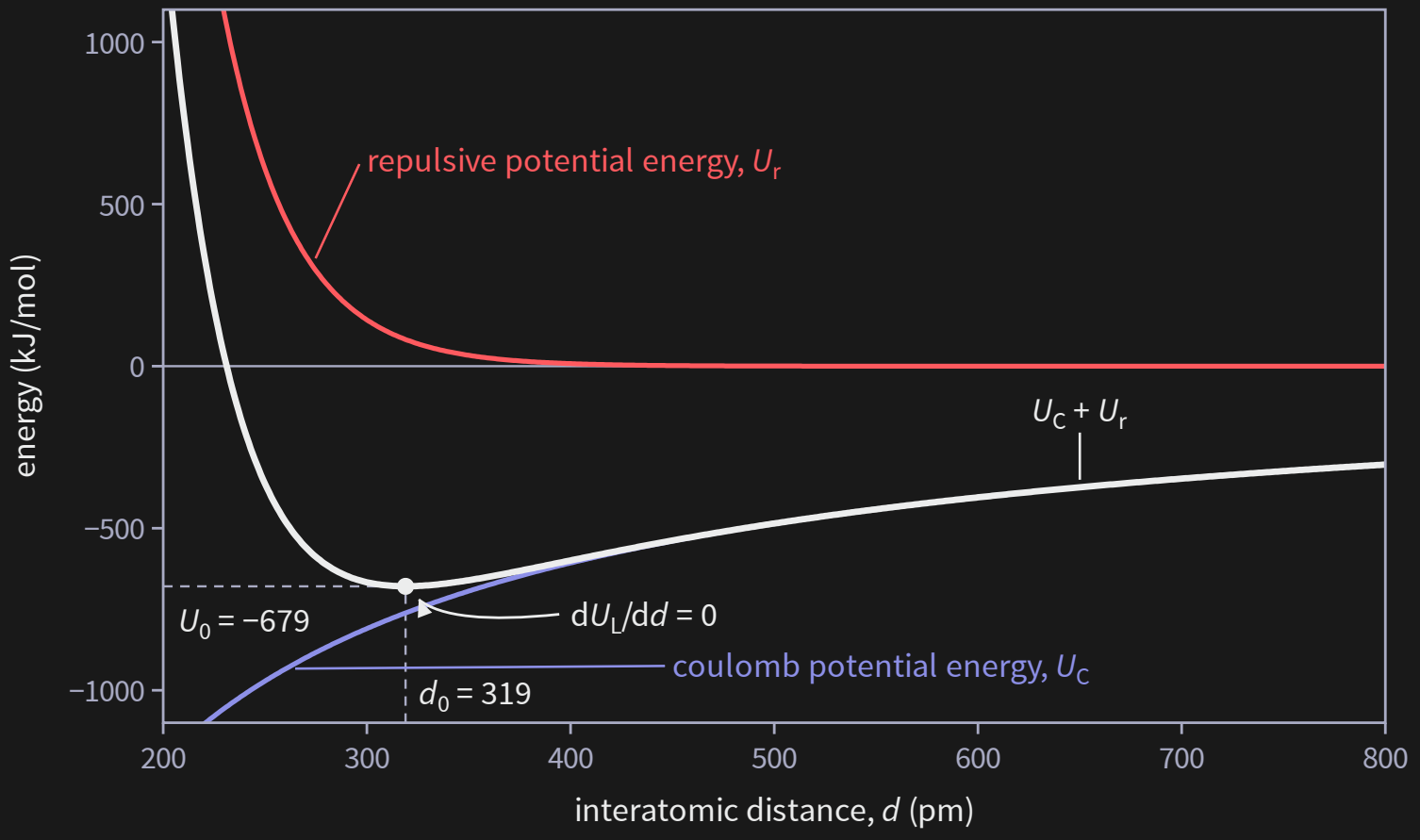
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Combining these two gives the Born-Mayer equation

$$U_L = U_C + U_r = \frac{z_1 z_2 e^2 N_{\mathrm{A}}}{4\pi\varepsilon_0 d} A + B e^{-d/\rho}$$

Per *Solid State Materials Chemistry*, §5.1.2, Eqs. (5.5) and (5.6).

# LATTICE ENERGY




Per *Solid State Materials Chemistry*, §5.1.2, Figure 5.2.

# BORN-MAYER EQUATION

$$U_L = \frac{z_1 z_2 e^2 N_\mathrm{A}}{4\pi\varepsilon_0 d} A + B e^{-d/\rho}$$

$$\frac{\mathrm{d}U_L}{\mathrm{d}d} = -\frac{z_1 z_2 e^2 N_\mathrm{A}}{4\pi\varepsilon_0 d_0^2} A - \frac{B e^{-d_0/\rho}}{\rho} = 0$$

$$U_L = -\frac{|z_1 z_2| e^2 N_\mathrm{A}}{4\pi\varepsilon_0 d_0} A \left(1 - \frac{\rho}{d_0}\right)$$

0.345 Å

Equilibrium distance between ions

Per *Solid State Materials Chemistry*, §5.1.2, Eqs. (5.6)–(5.8).

# SUMMARY – CHAPTER 5: IONIC BONDING

From point charges to a quantitative lattice energy, in eight steps.

| | |
|---|---|
| **Bonding refresher** | bridges earlier crystal structure topics to upcoming **band structure**. |
| **Ionic bonding model** | treat ions as **point charges**; interaction energy from **Coulomb's law**. |
| **Attraction vs. repulsion** | depends on **charge sign** and **distance**. |
| **Long-range nature** | Coulomb interactions require summing over **all shells of neighbors**. |
| **Madelung constant** | that summation converges to **A** (1.748 for NaCl rock salt). Higher coordination → larger A → stronger bonding; layered $CdCl_2$ and $CdI_2$ are reduced by added cation–cation repulsions. |
| **Lattice energy** | energy released when ions form a solid from infinite separation — **exothermic**. |
| **Born–Mayer model** | **Coulombic attraction** favors collapse, **exponential repulsion** prevents it; the minimum sets the **equilibrium distance $d_0$**. |
| **Born–Mayer equation** | quantitative lattice-energy estimates from **charges**, the **Madelung constant**, and **ionic radii**. |

# PART 2

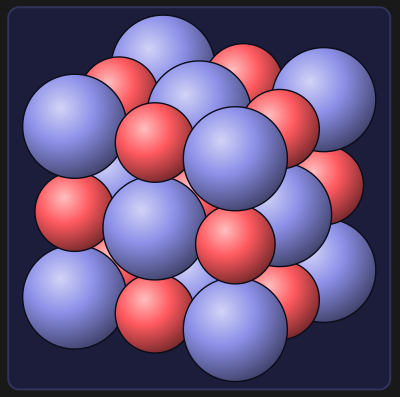
By the end of this lecture, you should be able to:

| | |
|---|---|
| **Born–Mayer equation** | recall its **form** and its **physical meaning**. |
| **Shannon radii** | use ionic radii to estimate the equilibrium distance $\mathbf{d_0}$. |
| **Lattice energy** | calculate it for an ionic compound — example: **KCl, rock salt structure**. |
| **Born–Haber cycle** | compare calculated lattice energies to the **experimental** values it gives. |
| **Corrections** | explain why Born–Mayer **underestimates**, and identify **dispersion** and **zero-point energy**. |
| **Size ratios** | relate cation/anion size to **coordination number** and **stable structures** (fluorite, rutile, layered). |
| **Anion polarizability** | describe how **induced dipoles** stabilize layered structures in heavier halides. |

# LATTICE ENERGY – EXAMPLE KCl

$$U_L = -\frac{|z_1 z_2| e^2 N_\mathrm{A}}{4\pi\varepsilon_0 d_0} A \left(1 - \frac{\rho}{d_0}\right)$$

Shannon radii
http://www.knowledgedoor.com/2/elements_handbook/shannon-prewitt_effective_ionic_radius.html



$a$ = 629 pm

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$$d_0 = r(\mathrm{K^+}) + r(\mathrm{Cl^-}) = 138\ \mathrm{pm} + 181\ \mathrm{pm} = 319\ \mathrm{pm}$$

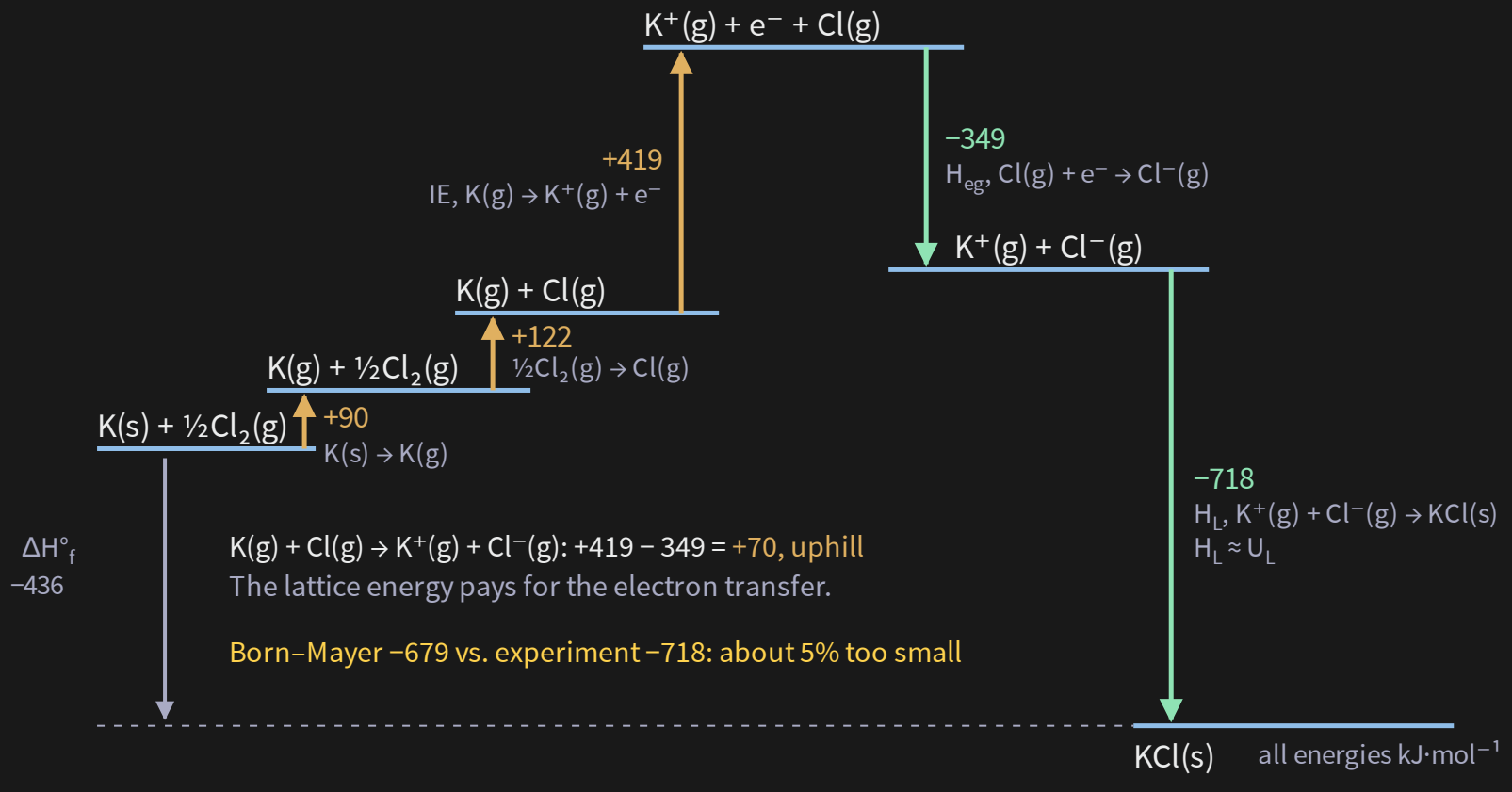
$$U_L = -\frac{(1)(1)\left(1.602\times10^{-19}\ \mathrm{C}\right)^2\left(6.022\times10^{23}\ \mathrm{mol^{-1}}\right)}{4\pi\left(8.8542\times10^{-12}\ \frac{\mathrm{C}}{\mathrm{V\,m}}\right)(319\times10^{-12}\ \mathrm{m})}\ 1.748\left(1 - \frac{34.5\ \mathrm{pm}}{319\ \mathrm{pm}}\right)$$

$$U_L = -\left(7.61\times10^{5}\ \mathrm{J\,mol^{-1}}\right)(1 - 0.108) = -6.79\times10^{5}\ \mathrm{J\,mol^{-1}} = -679\ \mathrm{kJ\,mol^{-1}}$$

Per *Solid State Materials Chemistry*, §5.1.2, Eq. (5.8); radii from the Shannon–Prewitt table linked above.

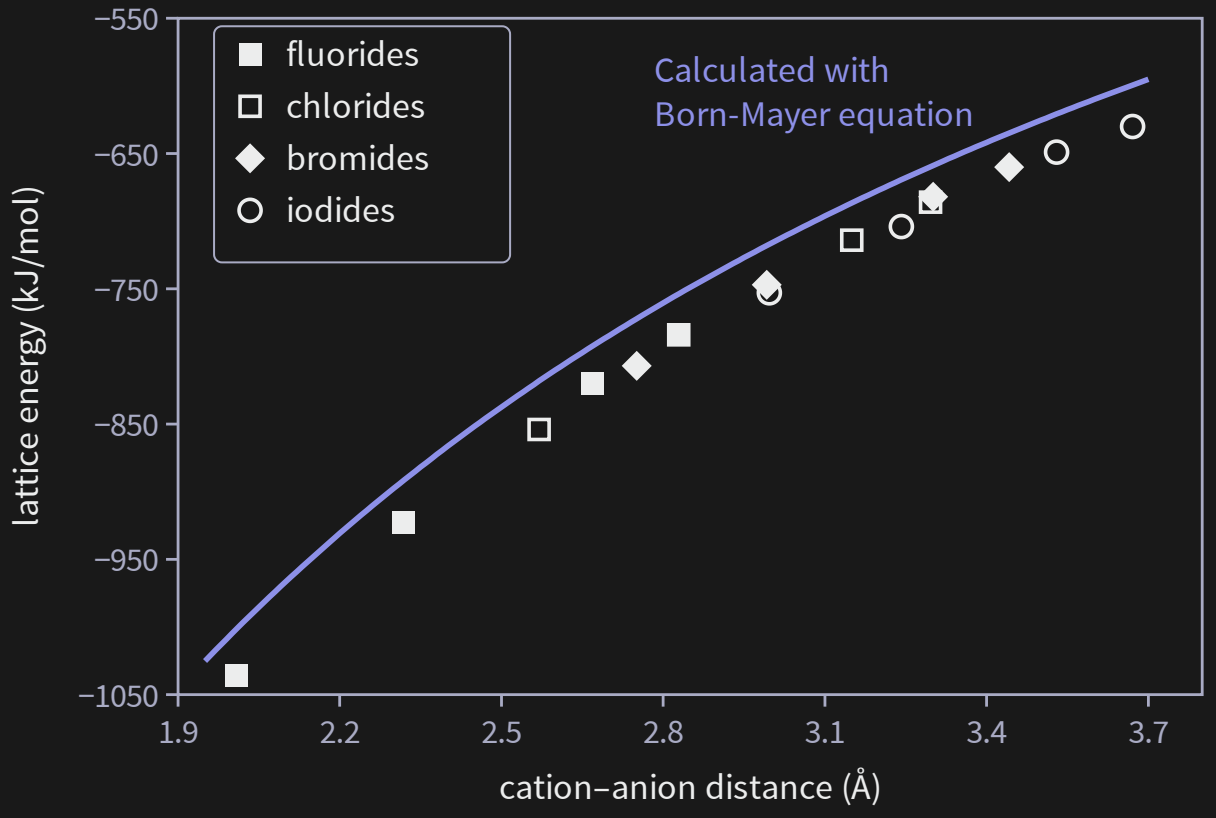
# BORN-HABER CYCLE

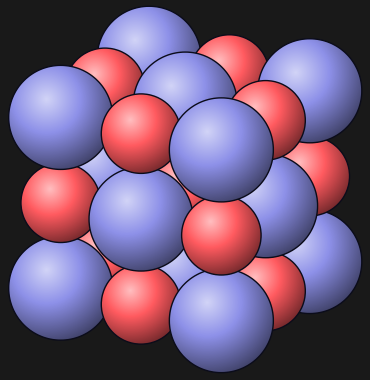
## Experimental determination of Lattice Energy




Per *Solid State Materials Chemistry*, §5.1.3, Figure 5.3.

# CALCULATED VS. EXPERIMENTAL LATTICE ENERGY



Alkali metal halides

Per *Solid State Materials Chemistry*, §5.1.3.

# COMPLETE LATTICE ENERGY EXPRESSION

$$U_{\mathrm{L}} = \underbrace{-\frac{|z_1 z_2| e^2 N_{\mathrm{A}}}{4\pi\varepsilon_0 d_0} A}_{[\mathrm{A}]} \underbrace{\left(1 - \frac{\rho}{d_0}\right)}_{[\mathrm{B}]} \underbrace{-\frac{N_{\mathrm{A}} C}{d_0^6}}_{[\mathrm{C}]} \underbrace{+ 2.25\, N_{\mathrm{A}} h\nu_{\max}}_{[\mathrm{D}]}$$

| | |
|---|---|
| **[A] Coulomb** | ion–ion attraction, negative, the **dominant** term |
| **[B] Repulsion** | core-orbital overlap, positive, **9–17%** of [A] |
| **[C] Dispersion** | van der Waals, $1/d^6$, stabilizes by **0.1–5%** |
| **[D] Zero point** | quantum, opposite sign to [C], **<1.5%** |

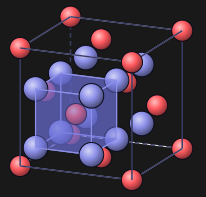
| kJ/mol | [A] | [B] | [C] | [D] | $U_{\mathrm{L}}$ |
|---|---|---|---|---|---|
| NaCl | −859 | +99 | −12 | +7 | **−766** |
| MgO | −4631 | +698 | −6 | +18 | **−3921** |

Per *Solid State Materials Chemistry*, §5.1.3.

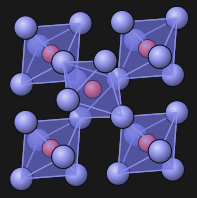
# WHICH STRUCTURE DOES AN $MX_2$ HALIDE ADOPT?

Observed structure by cation and anion size; ionic radii in pm.

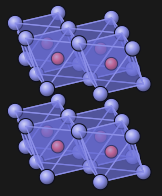
| Cation<br>ionic radius | $F^-$<br>133 | $Cl^-$<br>181 | $Br^-$<br>196 | $I^-$<br>220 |
|---|---|---|---|---|
| $Mg^{2+}$<br>72 | rutile | $CdI_2/CdCl_2$ | $CdI_2/CdCl_2$ | $CdI_2/CdCl_2$ |
| $Zn^{2+}$<br>74 | rutile | tetrahedral | tetrahedral | tetrahedral |
| $Mn^{2+}$<br>83 | rutile | $CdI_2/CdCl_2$ | $CdI_2/CdCl_2$ | $CdI_2/CdCl_2$ |
| $Ca^{2+}$<br>100 | fluorite | rutile | rutile | $CdI_2/CdCl_2$ |
| $Sr^{2+}$<br>118 | fluorite | fluorite | $PbCl_2$ | $SrI_2$ |
| $Ba^{2+}$<br>135 | fluorite | $PbCl_2$ | $PbCl_2$ | $PbCl_2$ |



fluorite, $Ca^{[8]}F_2^{[4]}$
$A = 2.519$



rutile, $Mg^{[6]}F_2^{[3]}$
$A = 2.408$



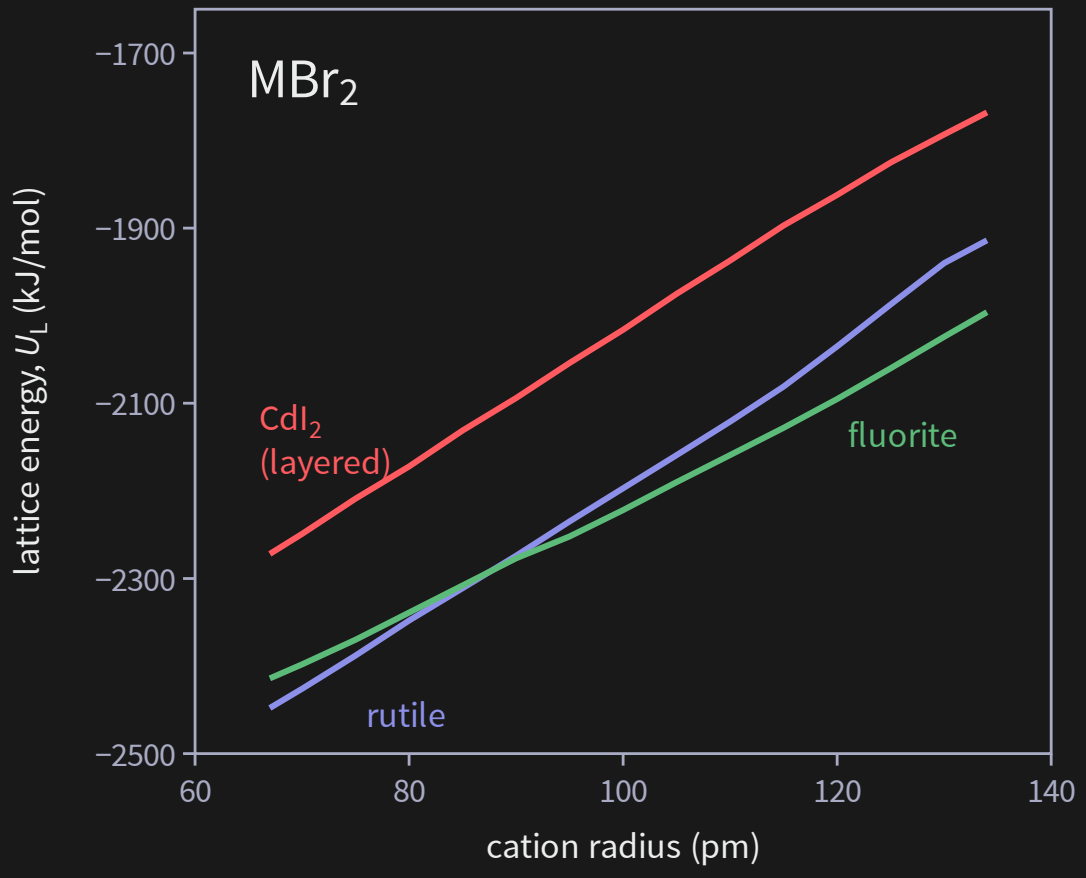
$Cd^{[6]}I_2^{[3]}$
$A = 2.192$

fluorite — CN 8 · rutile — CN 6 · $CdI_2/CdCl_2$ — layered, CN 6 · $PbCl_2$ and $SrI_2$ — CN 7 · tetrahedral — CN 4

Why would a structure with a smaller Madelung constant win, and why should that depend on ion size and electronegativity?

Madelung constants per *Solid State Materials Chemistry*, §5.1.1, Table 5.1. Zinc halides: $ZnCl_2$, J. Brynestad, H. L. Yakel, *Inorg. Chem.* **1978**, *17*, 1376; $ZnBr_2$, C. Chieh, M. A. White, *Z. Kristallogr.* **1984**, *166*, 189; $ZnI_2$, P.-H. Fourcroy et al., *Acta Cryst. B* **1978**, *34*, 3160. Other structure assignments and radii are the lecture's own.

# CALCULATED LATTICE ENERGY




Calculations with a rigid ionic model (similar to the Born-Mayer equation)

Rutile structure has the lowest E when the cation is small

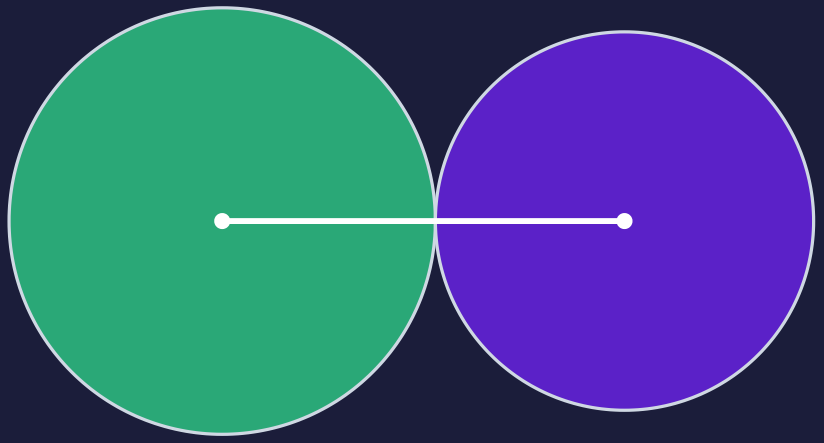
Fluorite structure has the lowest E when the cation is large

$CdI_2$ layered structure not stable for any cation size

M. Wilson, P. A. Madden, *J. Phys. Cond. Matt.* **1994**, *6*, 159–170.

# IONIC RADII VS CRYSTAL RADII

Shannon-Prewitt Ionic Radii
($O^{2-}$, $F^-$ chosen to match Pauling radii)

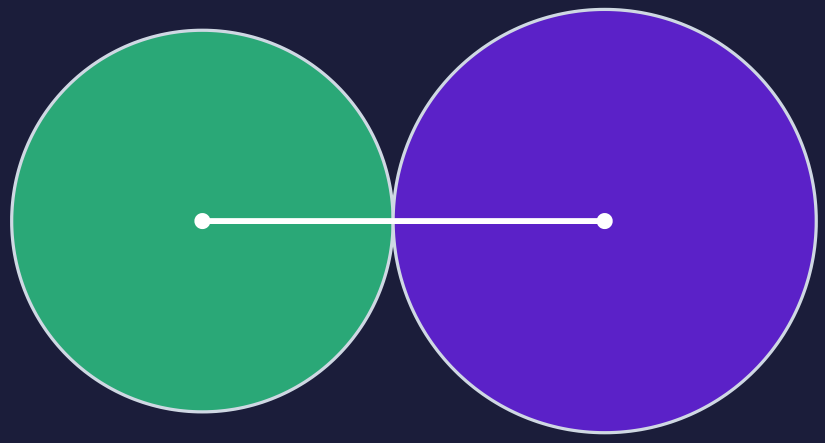


$F^-$
r = 133 pm
r = 1.33 Å

$Sr^{2+}$
r = 118 pm
r = 1.18 Å

d(Sr–F) = 133 + 118 pm
**d(Sr–F) = 251 pm**

Shannon-Prewitt Crystal Radii
($O^{2-}$, $F^-$ 14 pm smaller)



$F^-$
r = 119 pm
r = 1.19 Å

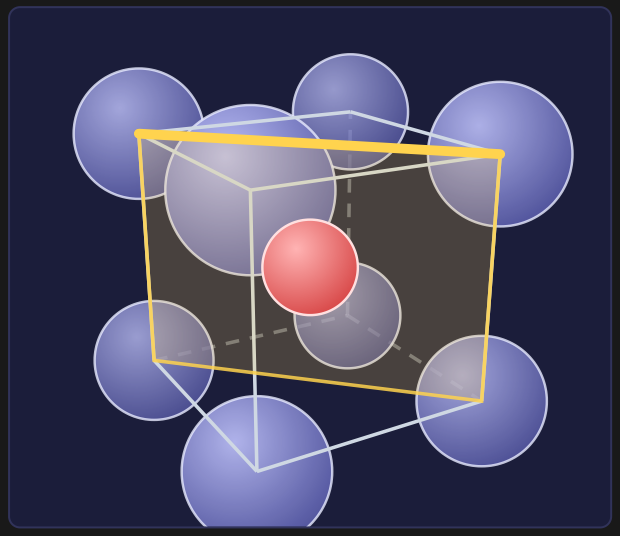
$Sr^{2+}$
r = 132 pm
r = 1.32 Å

d(Sr–F) = 119 + 132 pm
**d(Sr–F) = 251 pm**

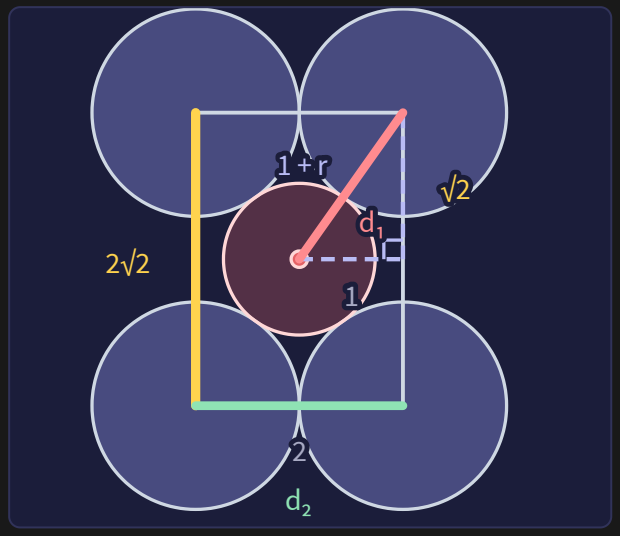
Same distance either way: the anion loses 14 pm and the cation gains the same 14 pm.

# HOW BIG A CATION FITS A CUBE OF 8?

Anion radius = 1. All lengths run between ion centers.



Cut vertically through the gold face diagonal.




At contact, the center-to-corner distance is 1 + r.

$$1 + r = \sqrt{1^2 + (\sqrt{2})^2} = \sqrt{3}$$

$$r = \sqrt{3} - 1 = 0.732$$

cube of 8 | octahedron of 6 | tetrahedron of 4

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**Now the real ions:** $Mg^{2+}$ in a cube of eight $F^-$, hard spheres with crystal radii r($Mg^{2+}$) = 86 pm and r($F^-$) = 119 pm.

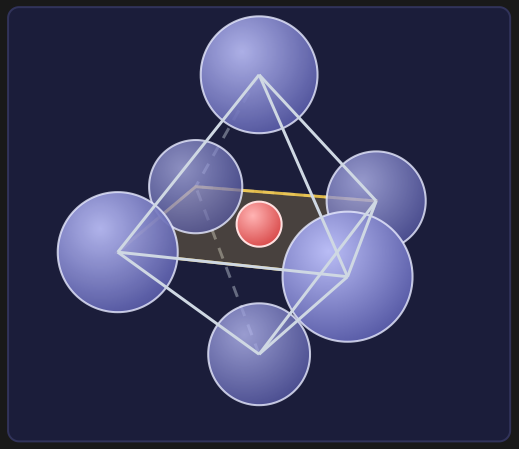
$d_1$, Mg–F center to corner: $86 + 119 = 205$ pm

$d_2$, F–F cube edge: $205 \times 2/\sqrt{3} = 237$ pm, vs. $2r(\mathrm{F}^-) = 238$ pm

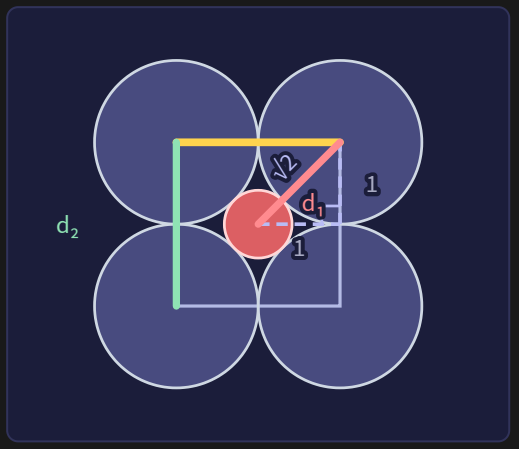
**86/119 = 0.72, just under the 0.732 limit derived above**

$Mg^{2+}$ is slightly too small for the cube, so the fluoride ions are already touching, with no room to close further.

# HOW BIG A CATION FITS AN OCTAHEDRON OF 6?



Six anions at the corners of an octahedron with the cation at the center.




The square of four anions at true size. The other two sit above and below the plane.

The four anions in the plane touch, so their centers form a square with sides of 2. The cation sits at the center, 1 across and 1 up from a corner, so the cation–anion distance is $\sqrt{1^2 + 1^2} = \sqrt{2}$.

When the cation just touches the anions, that distance is one anion radius plus one cation radius: $1 + r = \sqrt{2}$.

$$r = \sqrt{2} - 1 = 0.414$$

sodium in the NaCl structure

cube of 8 · 0.732 | **octahedron of 6 · 0.414** | tetrahedron of 4

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**Now the real ions:** $Mg^{2+}$ in an octahedron of six $F^-$, same crystal radii: r($Mg^{2+}$) = 86 pm, r($F^-$) = 119 pm.

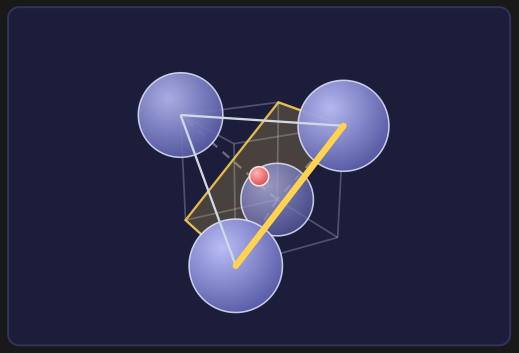
$d_1$, Mg–F center to corner: $86 + 119 = 205$ pm

$d_2$, F–F square edge: $2\,d_1 \sin 45^\circ = 290$ pm, vs. $2r(\mathrm{F}^-) = 238$ pm

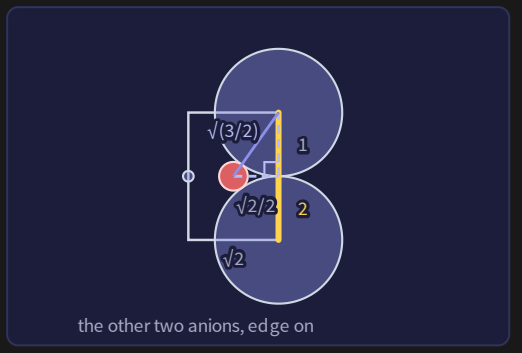
**86/119 = 0.72, well above the 0.414 limit derived above**

$Mg^{2+}$ is more than big enough for six, so the fluoride ions are not in contact and avoid core–core repulsion.

# HOW BIG A CATION FITS A TETRAHEDRON OF 4?



Four anions on alternate corners of a cube. The gold plane is the diagonal section shown at the right.




The gold diagonal section at true size, √2 by 2. Two anions and the cation lie in it. The other two anions touch it at the dot.

Touching anions: face diagonal $= 2$, so cube edge $e = \sqrt{2}$

Center to anion: $\sqrt{(\sqrt{2}/2)^2 + 1^2} = \sqrt{3/2}$

The anion takes 1, the cation the rest.

$$r = \sqrt{3/2} - 1 = 0.225$$

zinc in sphalerite

cube of 8 · 0.732 | octahedron of 6 · 0.414 | **tetrahedron of 4 · 0.225**

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**Now the real ions:** $Be^{2+}$ in a tetrahedron of four $S^{2-}$, crystal radii r($Be^{2+}$) = 41 pm, r($S^{2-}$) = 170 pm.

Be–S center to corner: $41 + 170 = 211$ pm

S–S tetrahedron edge: $\sqrt{8/3} \times 211 = 345$ pm, vs. $2r(S^{2-}) = 340$ pm

**41/170 = 0.24: below 0.414 for six, just above the 0.225 limit derived above**

Four sulfides just clear each other around $Be^{2+}$, and BeS takes the zinc blende structure.

# RADIUS RATIO, $\rho$

$$\rho = \frac{r_{\text{cation}}}{r_{\text{anion}}}$$

$\rho > 0.7$ — CN tends to be 8

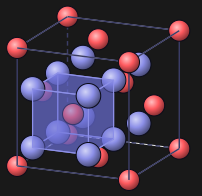
$0.7 > \rho > 0.4$ — CN tends to be 6

$\rho < 0.4$ — CN tends to be 4

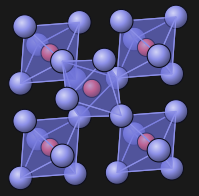
Cutoffs as the lecture teaches them, 0.7 and 0.4. *Solid State Materials Chemistry*, §1.4.2, note 17, gives the exact hard-sphere minima instead: $\sqrt{2} - 1 \approx 0.414$ for an octahedral hole and $(\sqrt{3}/\sqrt{2}) - 1 \approx 0.225$ for a tetrahedral hole.

# STRUCTURES OF $MX_2$ HALIDES

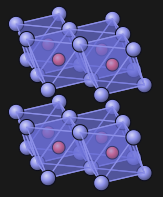
| Cation<br>crystal radius | $F^-$<br>119 | $Cl^-$<br>167 | $Br^-$<br>182 | $I^-$<br>206 |
|---|---|---|---|---|
| $Mg^{2+}$<br>86 | ρ = 0.72 | ρ = 0.51 | ρ = 0.47 | ρ = 0.42 |
| $Zn^{2+}$<br>88 | ρ = 0.74 | ρ = 0.53 | ρ = 0.48 | ρ = 0.43 |
| $Mn^{2+}$<br>97 | ρ = 0.82 | ρ = 0.58 | ρ = 0.53 | ρ = 0.47 |
| $Ca^{2+}$<br>114 | ρ = 0.96 | ρ = 0.68 | ρ = 0.63 | ρ = 0.55 |
| $Sr^{2+}$<br>132 | ρ = 1.11 | ρ = 0.79 | ρ = 0.73 | ρ = 0.64 |
| $Ba^{2+}$<br>149 | ρ = 1.25 | ρ = 0.89 | ρ = 0.82 | ρ = 0.72 |



fluorite, $Ca^{[8]}F_2^{[4]}$
$A = 2.519$



rutile, $Mg^{[6]}F_2^{[3]}$
$A = 2.408$

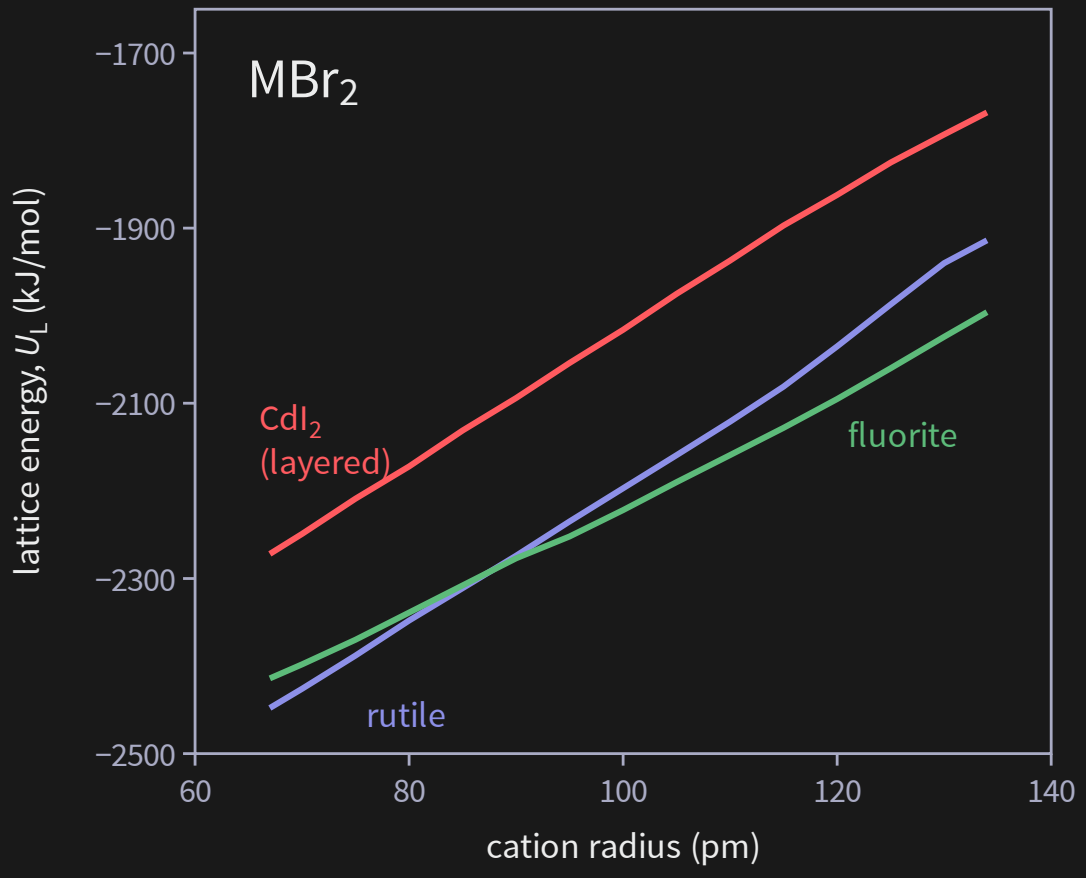


$Cd^{[6]}I_2^{[3]}$
$A = 2.192$

Green is CN 8, blue and pink CN 6, white CN 7, gold CN 4 — so what radius ratio does each compound have?

Structure assignments and radii are the lecture's own; each ratio is the header row's crystal radii divided cell by cell.

# CALCULATED LATTICE ENERGY




Calculations with a rigid ionic model (similar to the Born-Mayer equation)

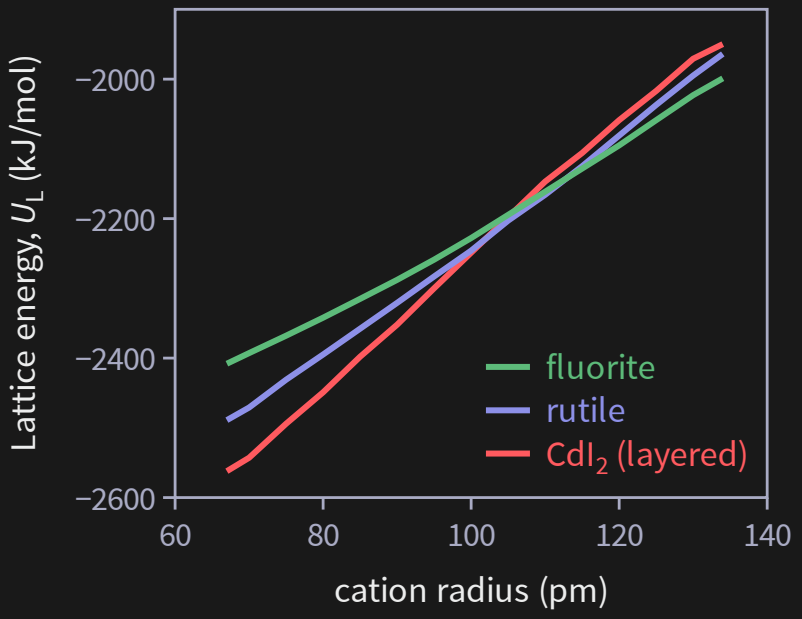
Rutile structure has the lowest E when the cation is small

Fluorite structure has the lowest E when the cation is large

$CdI_2$ layered structure not stable for any cation size

M. Wilson, P. A. Madden, *J. Phys. Cond. Matt.* **1994**, *6*, 159–170.

# CALCULATED LATTICE ENERGY, $MBr_2$ HALIDES

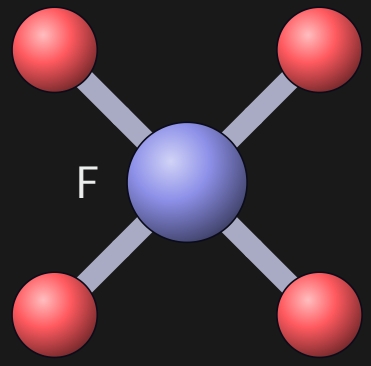


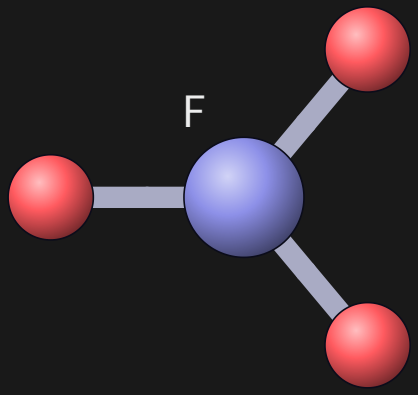

Introduce polarization of the electron cloud surrounding the anion (creating an induced dipole)

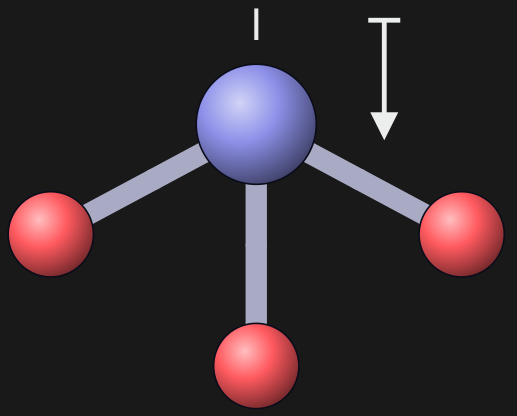
**Now the layered $CdI_2$/$CdCl_2$ structures emerge as the lowest energy structure for small cations.**

M. Wilson, P. A. Madden, *J. Phys. Cond. Matt.* **1994**, *6*, 159–170.

# ANION ENVIRONMENT




**Fluorite**

Anion environment:
tetrahedral

Site symmetry:
$\bar{4}3m$ ($T_d$)

No anion polarization

**Rutile**

Anion environment:
~trigonal planar

Site symmetry:
$2mm$ ($C_{2v}$)

Minimal anion polarization

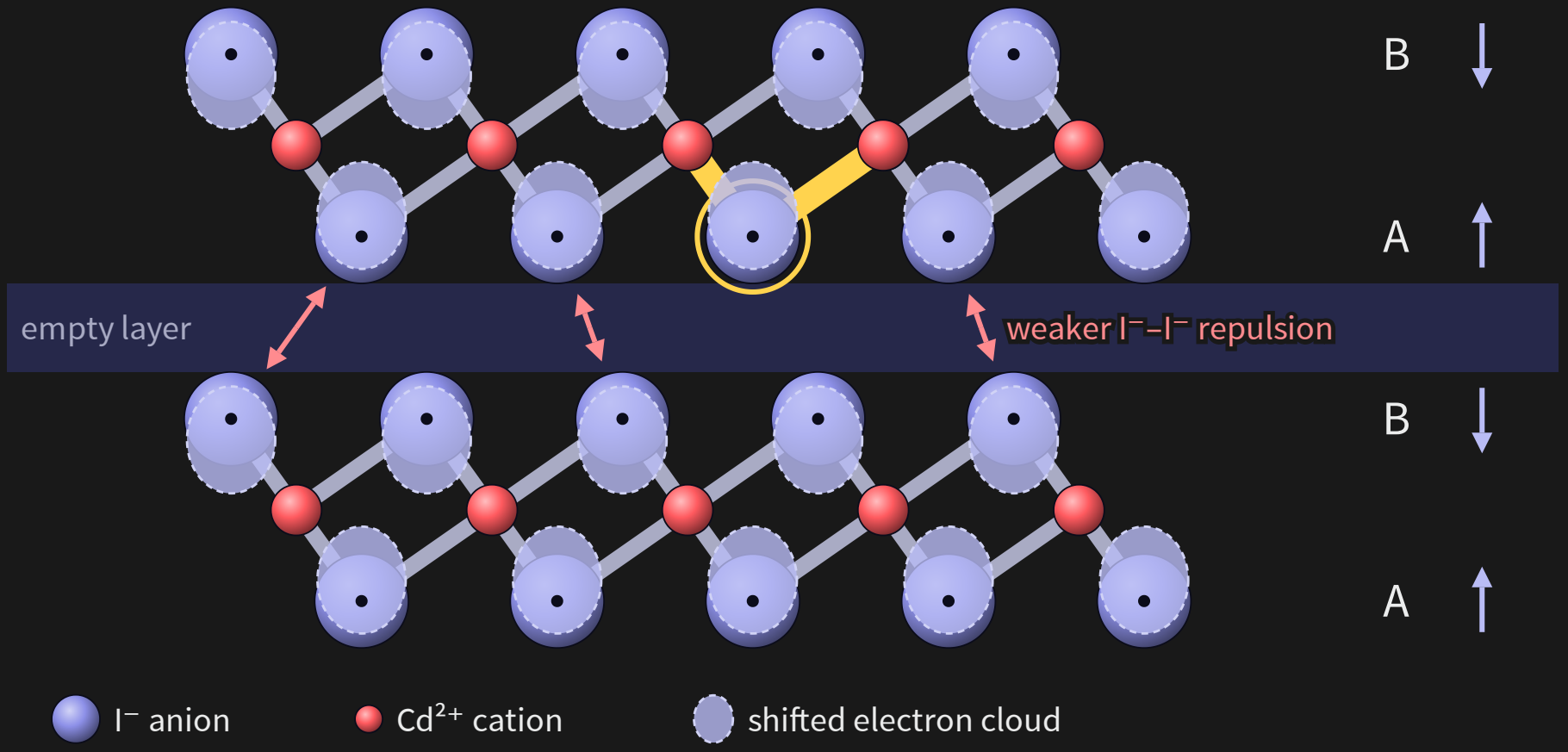
**$CdI_2$**

Anion environment:
trigonal pyramidal

Site symmetry:
$3m$ ($C_{3v}$)

Significant anion polarization

# ANION POLARIZATION

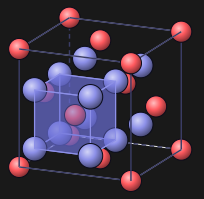



Each $Cd^{2+}$ sits symmetrically among its $I^-$, but each $I^-$ has all its $Cd^{2+}$ neighbours on one side.
The induced dipole pulls each anion's negative charge toward the layer that contains the cations.
That reduces the repulsion between anions across the empty layer.

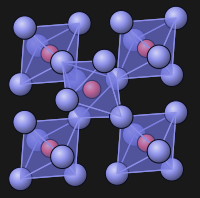
# STRUCTURES OF $MX_2$ HALIDES

The same map once more, now read down the halide columns for polarizability; radii in pm.

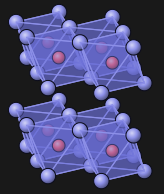
| Cation<br>crystal radius | $F^-$<br>119 | $Cl^-$<br>167 | $Br^-$<br>182 | $I^-$<br>206 |
|---|---|---|---|---|
| $Mg^{2+}$<br>86 | rutile | $CdI_2/CdCl_2$ | $CdI_2/CdCl_2$ | $CdI_2/CdCl_2$ |
| $Zn^{2+}$<br>88 | rutile | tetrahedral | tetrahedral | tetrahedral |
| $Mn^{2+}$<br>97 | rutile | $CdI_2/CdCl_2$ | $CdI_2/CdCl_2$ | $CdI_2/CdCl_2$ |
| $Ca^{2+}$<br>114 | fluorite | rutile | rutile | $CdI_2/CdCl_2$ |
| $Sr^{2+}$<br>132 | fluorite | fluorite | $PbCl_2$ | $SrI_2$ |
| $Ba^{2+}$<br>149 | fluorite | $PbCl_2$ | $PbCl_2$ | $PbCl_2$ |



fluorite, $Ca^{[8]}F_2^{[4]}$
$A = 2.519$



rutile, $Mg^{[6]}F_2^{[3]}$
$A = 2.408$



$Cd^{[6]}I_2^{[3]}$
$A = 2.192$

fluorite — CN 8 · rutile — CN 6 · $CdI_2/CdCl_2$ — layered, CN 6 · $PbCl_2$ and $SrI_2$ — CN 7 · tetrahedral — CN 4

Structure assignments and radii are the lecture's own.

# SUMMARY

From the Born–Mayer equation to anion polarization: what the second half of the lecture settled.

| | |
|---|---|
| **Born–Mayer equation** | Combines Coulomb attraction with a short-range repulsive term to approximate lattice energy. |
| **Worked example** | For KCl, calculated lattice energy ≈ −679 kJ/mol vs. experimental −718 kJ/mol (Born–Haber). |
| **Shannon radii** | Provide coordination-specific values to estimate $\mathbf{d_0}$. |
| **Accuracy** | The model systematically underestimates lattice energies by ~3–6%; adding dispersion and zero-point energy terms improves accuracy slightly, but the main trend is well captured. |
| **Radius ratio rule** | Smaller cations (or larger anions) lower coordination numbers → 8 → 6 → 4. |
| **Structure stability** | Large cations + small anions → fluorite (CN = 8); small cations → rutile (CN = 6); large, polarizable anions ($Br^-$, $I^-$) → layered $CdI_2$-type structures, stabilized by **anion polarization**. |
| **Polarization symmetry** | Symmetry of cation arrangement dictates whether polarization cancels (fluorite, rutile) or enhances stability (layered). |

# PRACTICE QUESTIONS

Work the Lecture 11 practice questions before the next class.

Open the Lecture 11 practice questions