



UNIVERSITÀ
DEGLI STUDI DI TRIESTE



Scienza dei Materiali

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Dipartimento di Ingegneria e Architettura

A.A. 2020-21

Lezione 2

Legame chimico (ripasso)

Legami Primari (tra atomi)

forze intramolecolari

- si manifestano all'interno di una molecola (o insieme atomi/ioni)
- più forti ($150-4000 \text{ kJ/mol}$)
- fortemente direzionali
- a corto raggio
- determinano le proprietà CHIMICHE della materia

interazione tra atomi



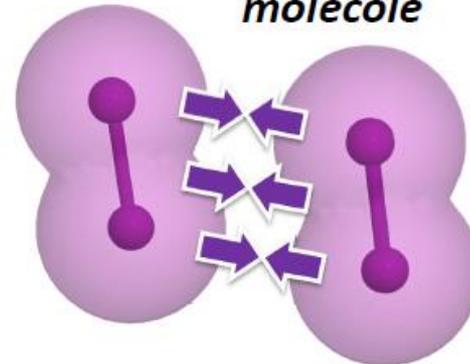
Importanti per i solidi inorganici

Legami Secondari (tra molecole)

forze intermolecolari

- forze che si manifestano tra entità molecolari (uguali o diverse tra loro)
- più deboli ($0.05- 30 \text{ kJ/mol}$)
- meno (non-) direzionali
- ad ampio raggio
- determinano le proprietà FISICHE della materia

interazione tra molecole

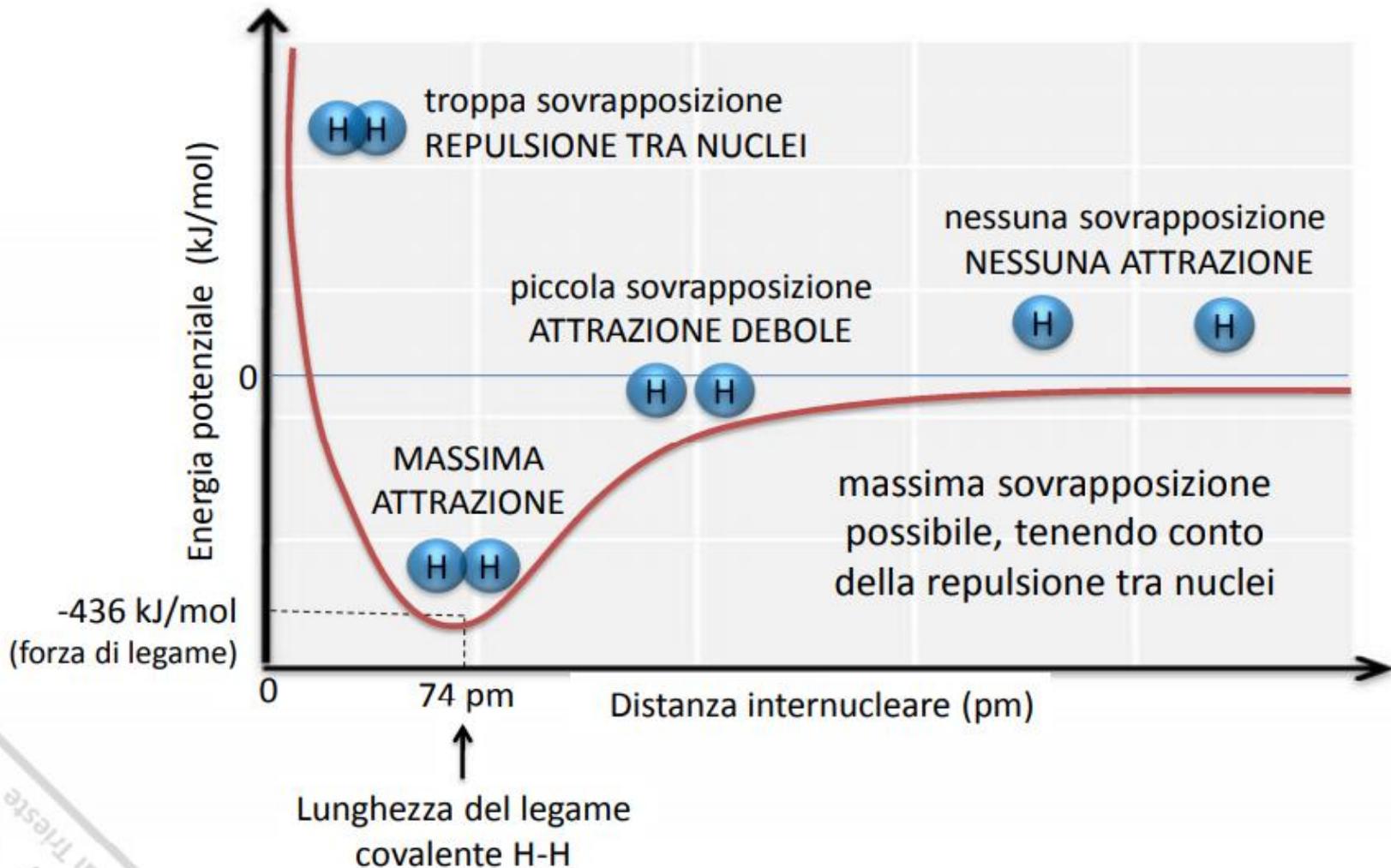


Importanti nei polimeri

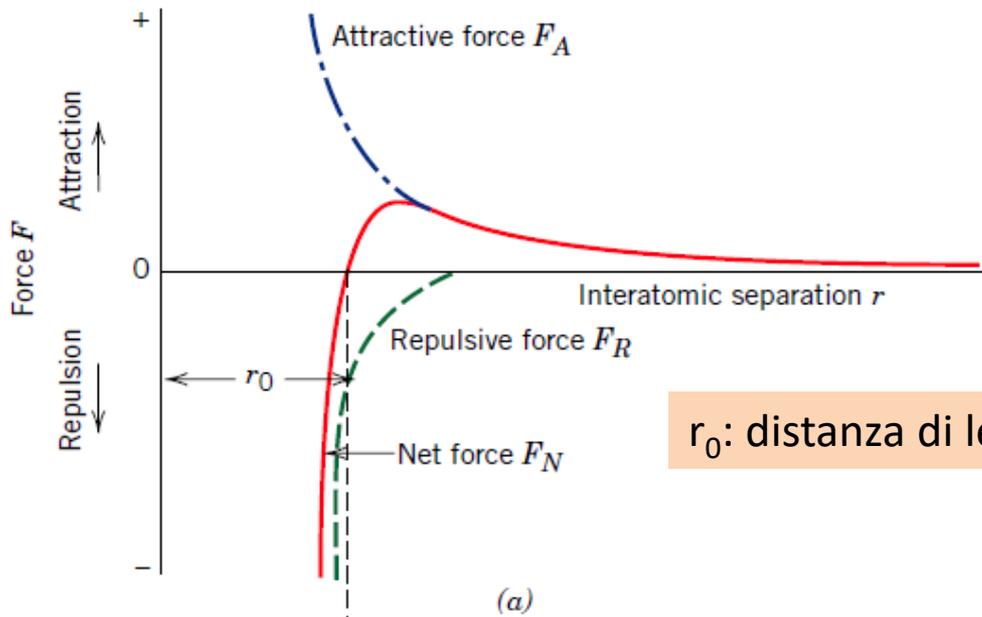
slides
delle lezioni
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A.

Energia potenziale per coppie di atomi interagenti

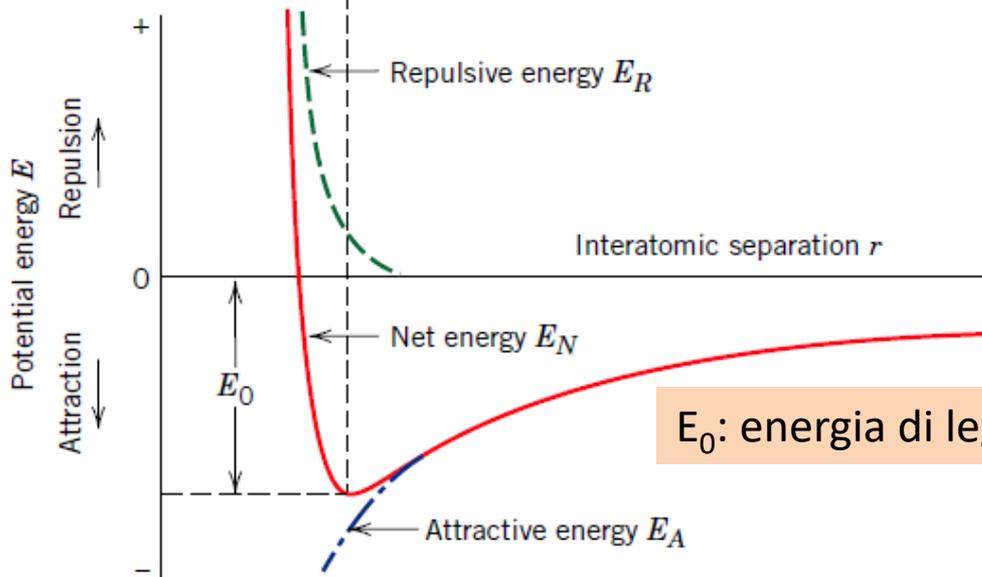


Energia potenziale e Forza di Legame



r_0 : distanza di legame

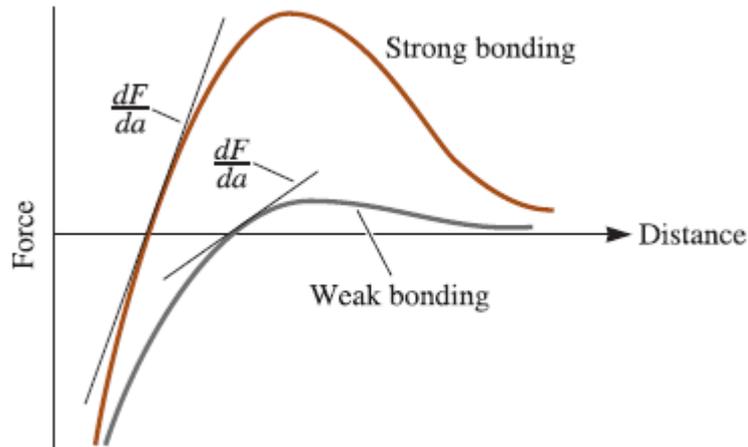
$$F_N = F_A + F_R$$



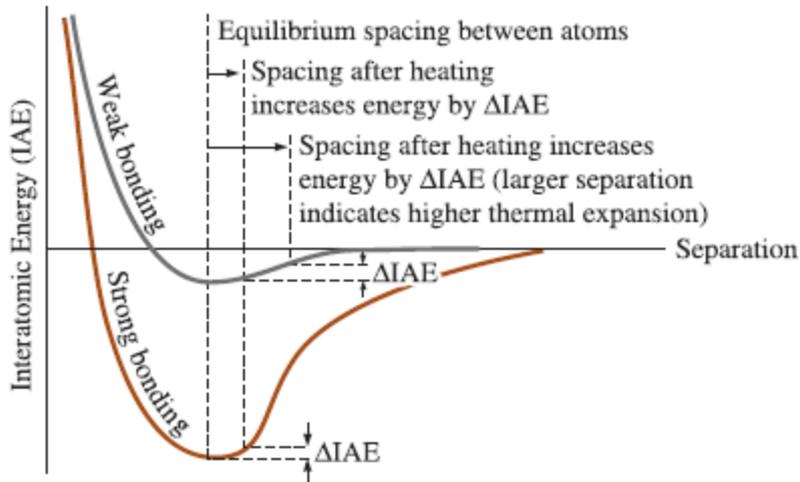
E_0 : energia di legame

$$\begin{aligned}
 E_N &= \int_{\infty}^r F_N dr \\
 &= \int_{\infty}^r F_A dr + \int_{\infty}^r F_R dr \\
 &= E_A + E_R
 \end{aligned}$$

Correlazione con le proprietà dei materiali



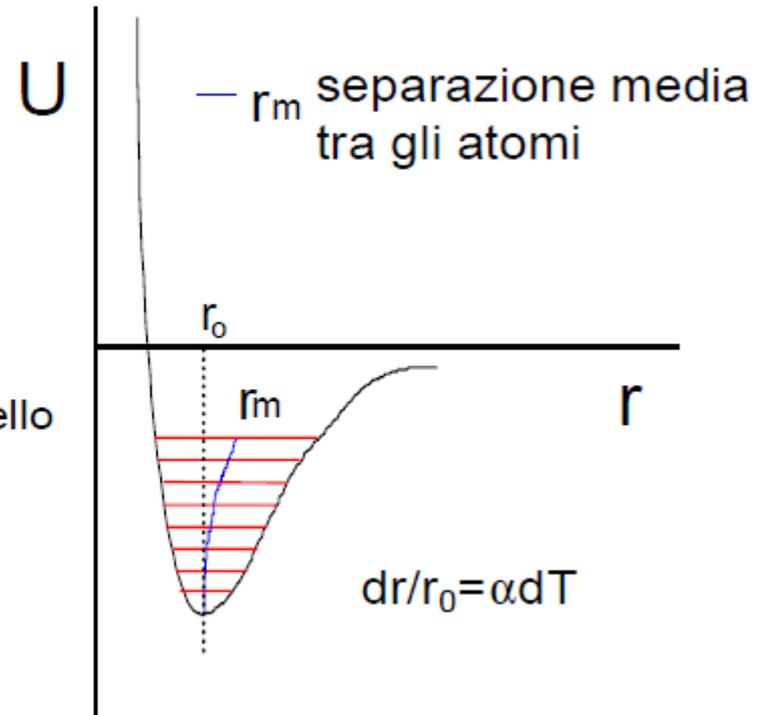
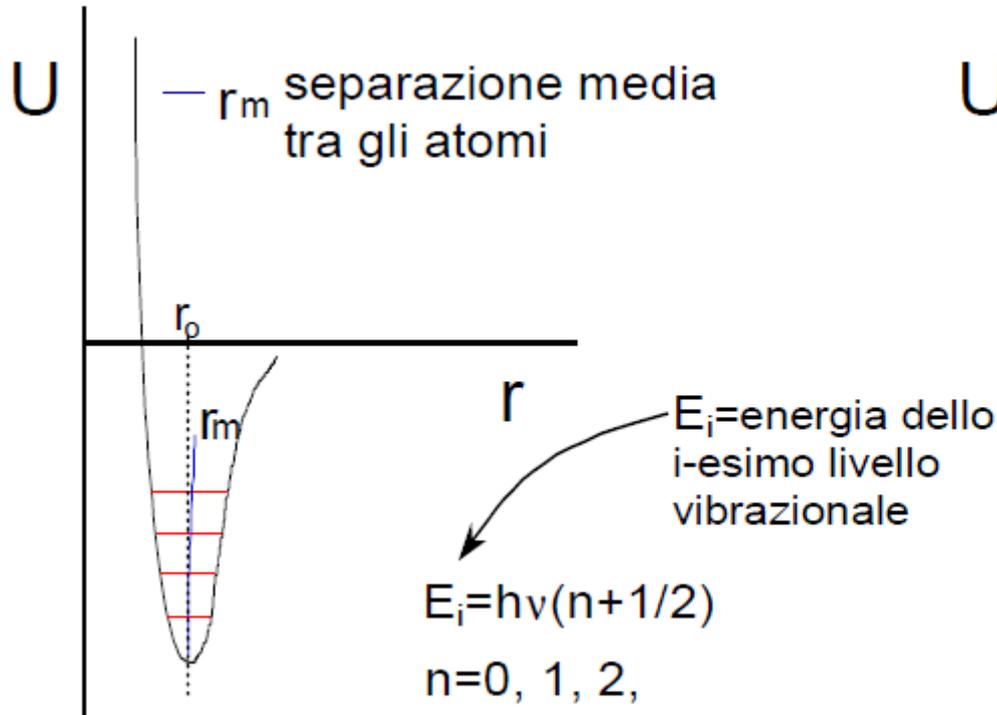
- Pendenza elevata ad r_0 : elevata **rigidità** (modulo di Young)
- Rigidità dipende poco da altri parametri del materiale



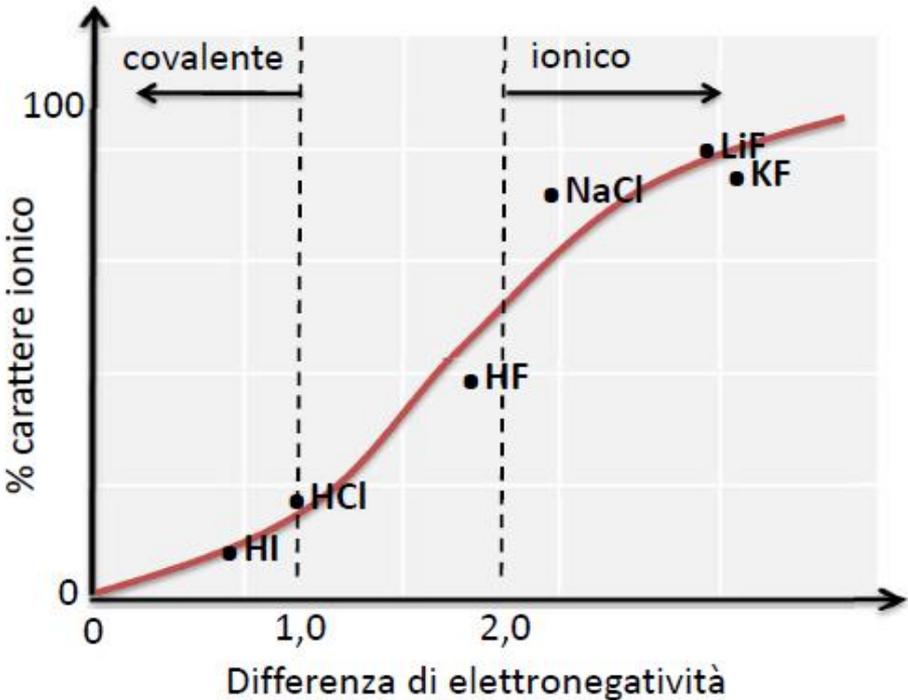
- Elevata energia di legame E_0 : elevata **temperatura di fusione**
- Curva dell'energia profonda e stretta: bassa **espansione termica**

Correlazione con le proprietà dei materiali

- Curva dell'energia profonda e stretta: bassa **espansione termica**
- L'espansione termica è dovuta alla asimmetria della gola nella curva dell'energia



Legami: covalente puro, covalente polare, ionico

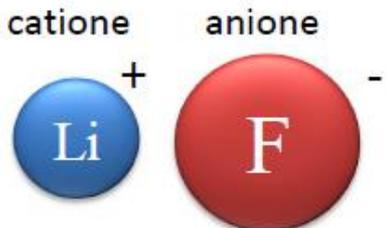


$$\% \text{ ionic character} = \{1 - \exp[-(0.25)(X_A - X_B)^2]\} \times 100$$

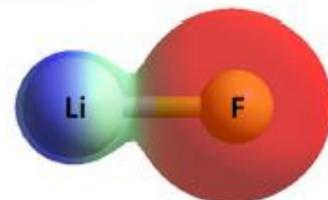
$$\mu = Qr$$

se conosco momento dipolare e distanza di legame posso ricavare Q (frazione di carica)

legame ionico



LiF ionico
Δχ = 3.0



H₂ covalente puro HF covalente polare
Δχ = 0 Δχ = 1.8

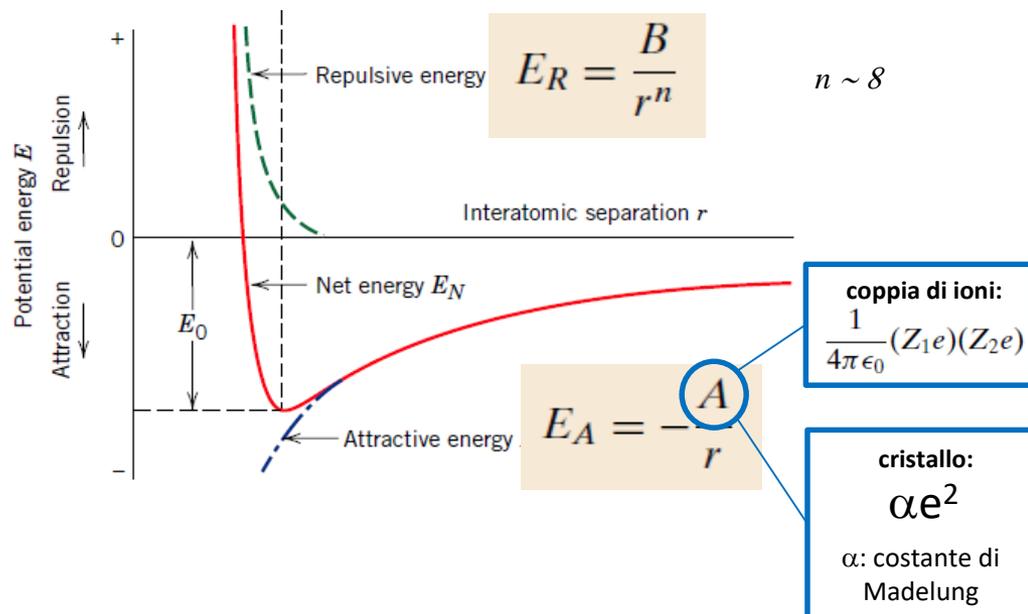
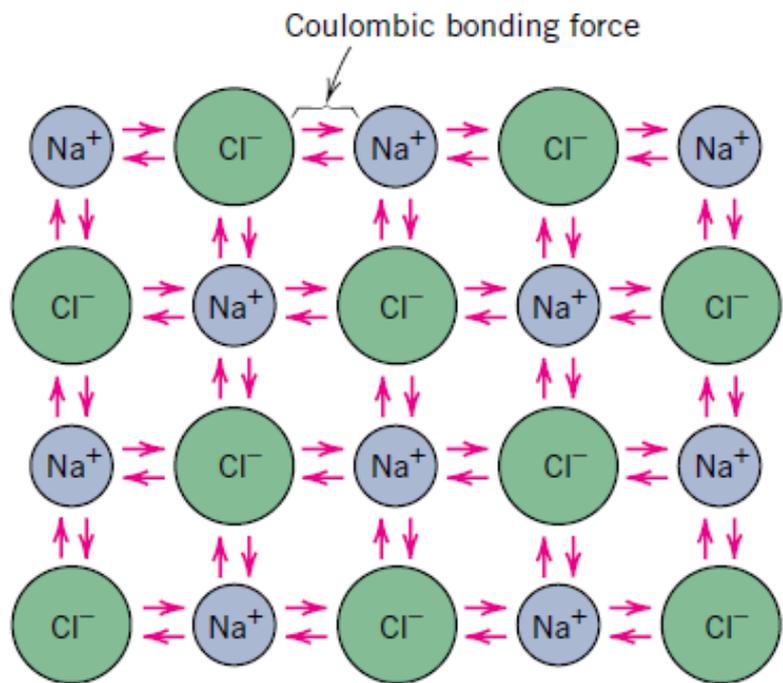


Aumento del carattere ionico

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Legame ionico → Cristallo Ionico



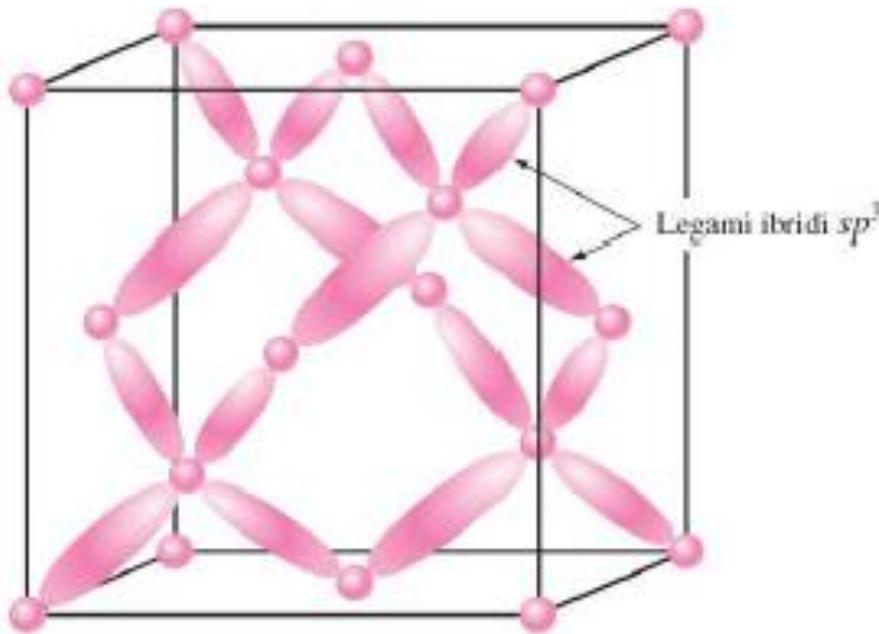
- Il legame non è direzionale
- Elevati punti di fusione
- Scarsa deformabilità
- Scarsa conducibilità elettrica

Costante di Madelung:

tiene conto di tutte le interazioni ione-ione nell'intero cristallo

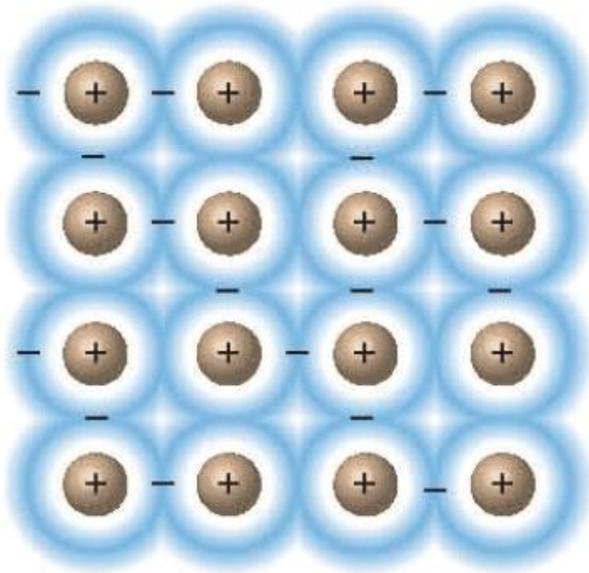
CsCl	1,7627
NaCl	1,7476
ZnS	1,6381

Legame covalente → Cristallo Covalente



- Forza di legame può variare molto
- Legami direzionali
- Scarsa deformabilità
- Elevata durezza
- Spesso degradano piuttosto che fondere

Legame metallico → Cristallo metallico



legame metallico

legame tra elementi poco
elettronegativi (metalli)
caratterizzato dalla
delocalizzazione degli elettroni
di legame su più nuclei
("mare di elettroni")

- Elevata conducibilità elettrica
- Elevata conducibilità termica
- Elevata deformabilità
- Temperatura di fusione dipende da struttura elettronica

Metalli: confronto energia di legame

Tabella 2.9 Energie di legame, temperature di fusione e configurazioni elettroniche dei metalli del quarto periodo della tavola periodica degli elementi

Elemento	Configurazione elettronica	Energia di legame		Temperatura di fusione (°C)
		kJ/mol	kcal/mol	
K → Z=19	$4s^1$	89.6	21.4	63.5
Ca	$4s^2$	177	42.2	851
Sc	$3d^1 4s^2$	342	82	1397
Ti	$3d^2 4s^2$	473	113	1660
V	$3d^3 4s^2$	515	123	1730
Cr	$3d^5 4s^1$	398	95	1903
Mn	$3d^5 4s^2$	279	66.7	1244
Fe	$3d^6 4s^2$	418	99.8	1535
Co	$3d^7 4s^2$	383	91.4	1490
Ni	$3d^8 4s^2$	423	101	1455
Cu	$3d^{10} 4s^1$	339	81.1	1083
Zn	$4s^2$	131	31.2	419
Ga	$4s^2 4p^1$	272	65	29.8
Ge → Z=32	$4s^2 4p^2$	377	90	960

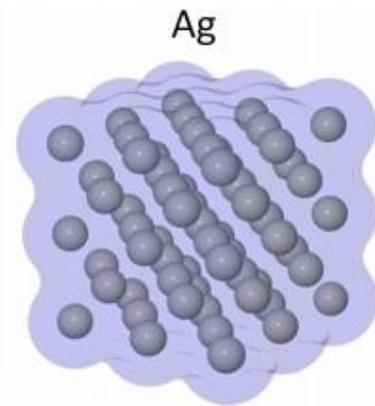
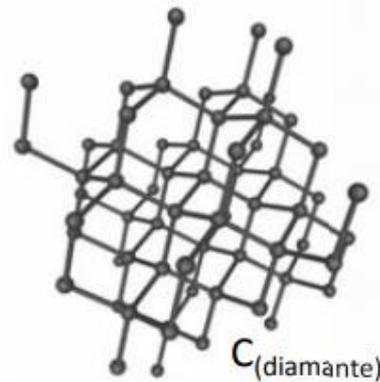
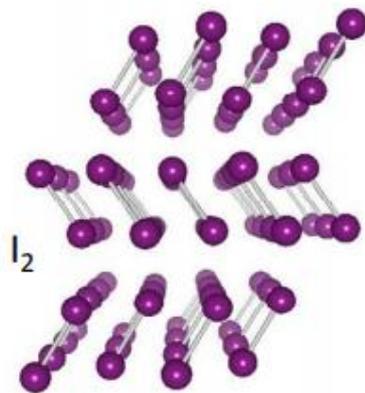
Energie di legame a confronto

<i>Bonding Type</i>	<i>Substance</i>	<i>Bonding Energy</i>		<i>Melting Temperature (°C)</i>
		<i>kJ/mol</i>	<i>eV/Atom, Ion, Molecule</i>	
Ionic	NaCl	640	3.3	801
	MgO	1000	5.2	2800
Covalent	Si	450	4.7	1410
	C (diamond)	713	7.4	>3550
Metallic	Hg	68	0.7	-39
	Al	324	3.4	660
	Fe	406	4.2	1538
	W	849	8.8	3410
van der Waals	Ar	7.7	0.08	-189
	Cl ₂	31	0.32	-101
Hydrogen	NH ₃	35	0.36	-78
	H ₂ O	51	0.52	0

(1) natura del legame chimico

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Tipo di solido	Particelle in un solido	Forze tra le particelle	Proprietà fisiche	Esempi
Ionico	Cationi e anioni	Attrazioni elettrostatiche	Duri e lucenti, alto punto di fusione, bassa conducibilità di calore ed elettricità	NaCl, CaO, MgBr ₂
Molecolare	Atomi o molecole	Forze di London, dipolo-dipolo, e/o legame idrogeno	Leggermente teneri, punto di fusione basso o medio, bassa conducibilità di calore ed elettricità	CH ₄ , C ₆ H ₁₂ O ₆ (glucosio), H ₂ O, Kr
Struttura covalente	Atomi	Legame covalente	Molto duri, punto di fusione elevato, bassa conducibilità di calore ed elettricità	C (diamante), SiO ₂ (quarzo), SiC, BN
Metallico	Atomi	Legame metallico	Teneri o duri, da basso ad alto punto di fusione, buona conducibilità del calore ed elettrica	Na, Fe, Au, Ag, Al

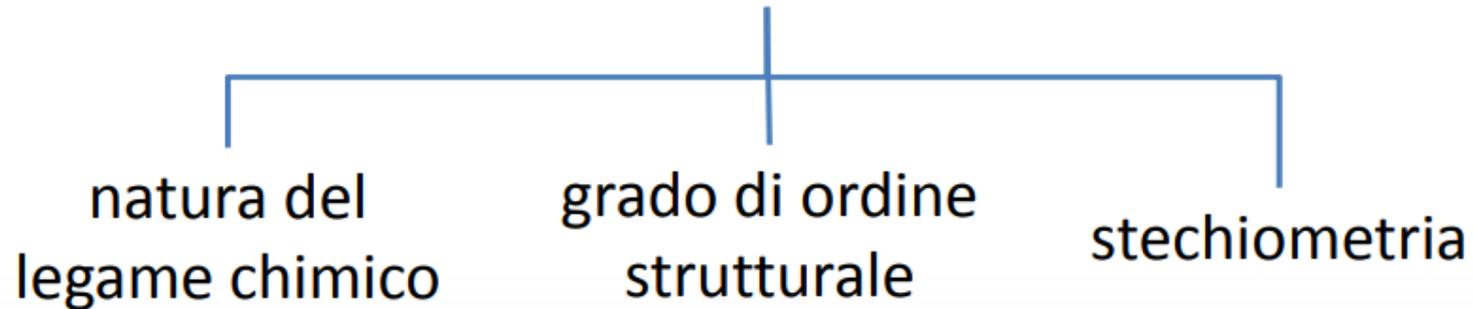


stato solido

*stato della materia nella quale i corpi hanno
forma e volume propri*



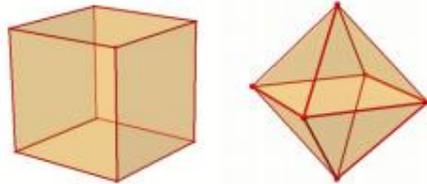
solidi classificabili in base a **3 criteri**



solidi cristallini

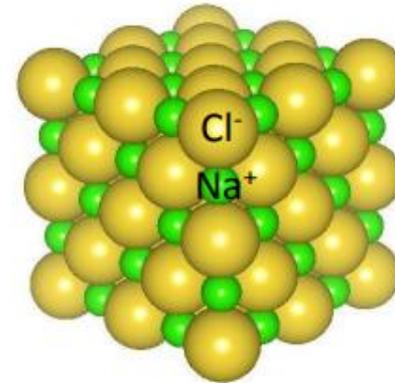
descrizione macroscopica

*aspetto esterno (macroscopico) del
cristallo → ABITO CRISTALLINO*



*uno stesso composto può presentare
diversi abiti cristallini
ma gli angoli tra le facce del cristallo
rimangono uguali*

descrizione microscopica



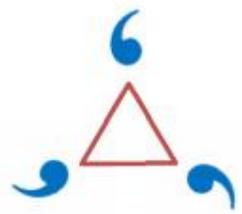
*l'abito cristallino dipende
dalla disposizione spaziale
degli atomi o molecole nella
struttura cristallina*

elementi ed operazioni di simmetria

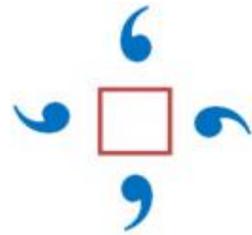
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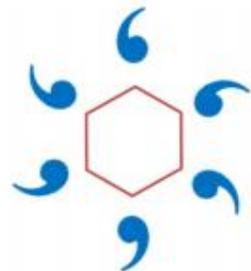
asse binario



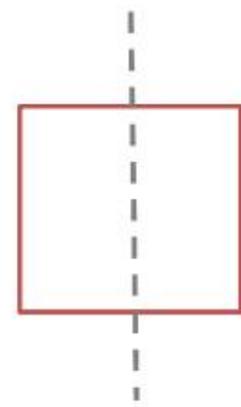
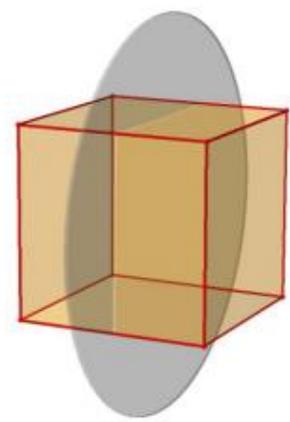
asse ternario



asse quaternario



asse senario



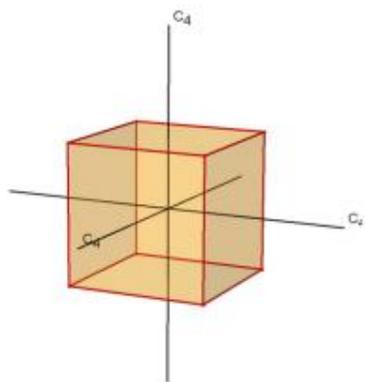
piano di riflessione

*la "regolarità" della forma dei solidi
cristallini si può descrivere con la teoria
matematica della simmetria*

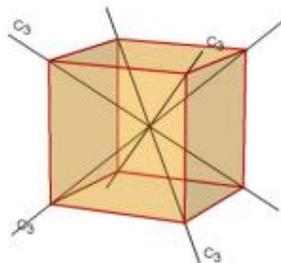
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elementi di simmetria

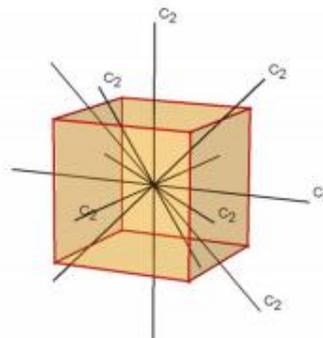
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delle lezioni
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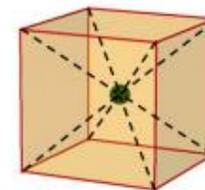
3 assi quaternari



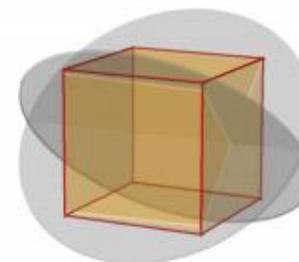
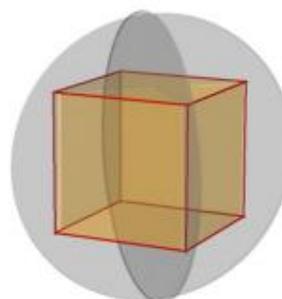
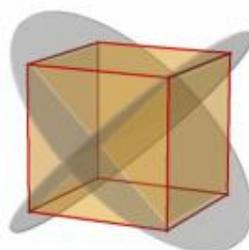
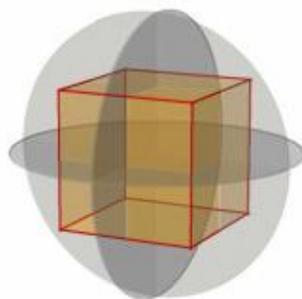
4 assi ternari



6 assi binari



1 centro di
inversione



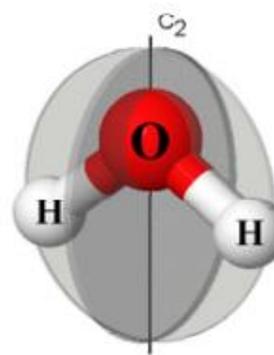
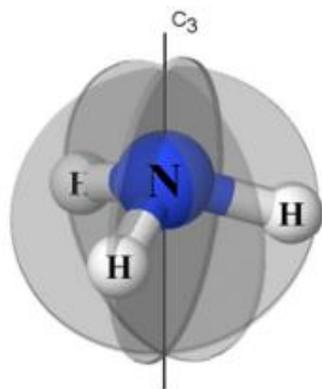
9 piani di riflessione

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elementi ed operazioni di simmetria

*la teoria della simmetria si può applicare
anche alle strutture molecolari*

slides
delle lezioni
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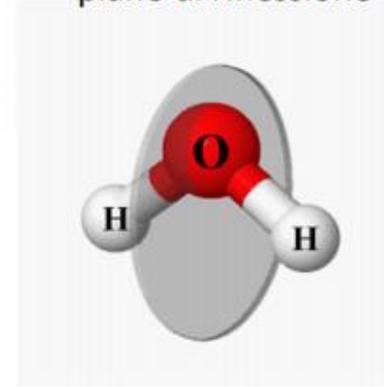
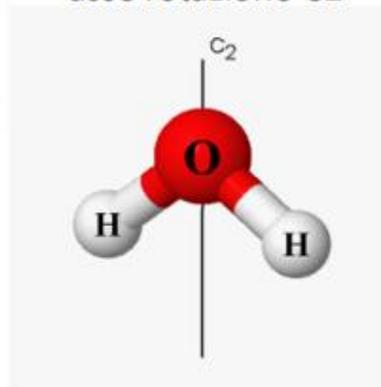
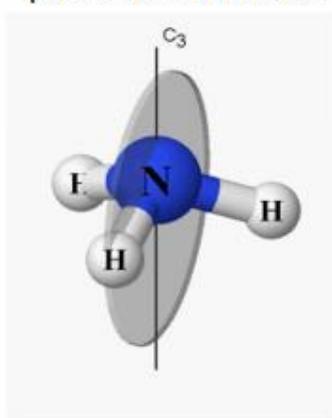
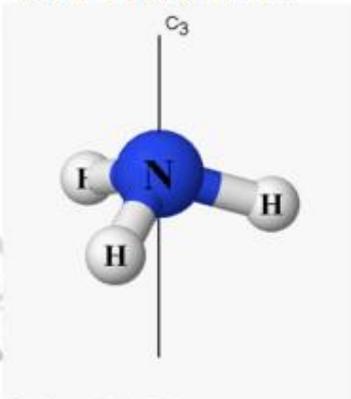


asse rotazione C3

piano di riflessione

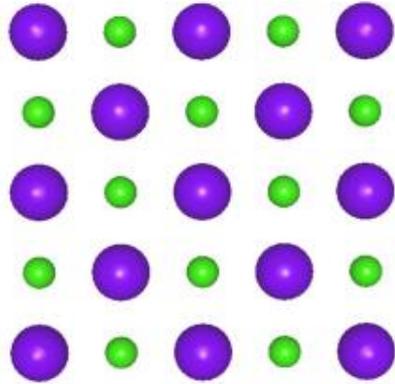
asse rotazione C2

piano di riflessione

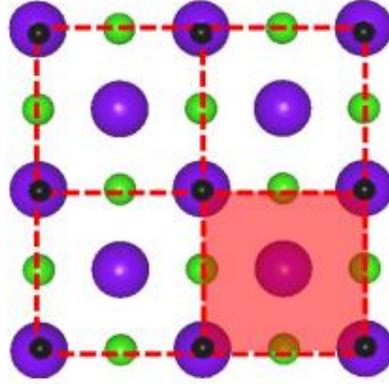


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teste

descrizione microscopica: reticolo cristallino

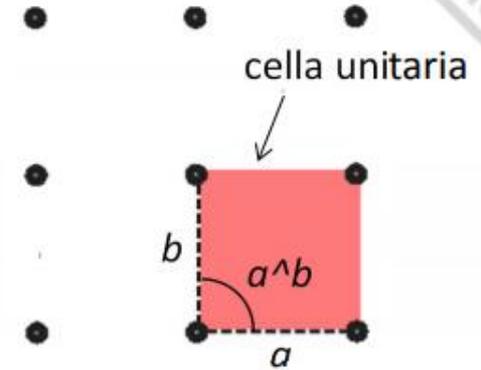


*disposizione regolare
atomi o molecole
nello spazio*



*ad ogni punto del
cristallo con lo stesso
"intorno" è associato
un punto del reticolo*

a, b, a^b costanti di cella

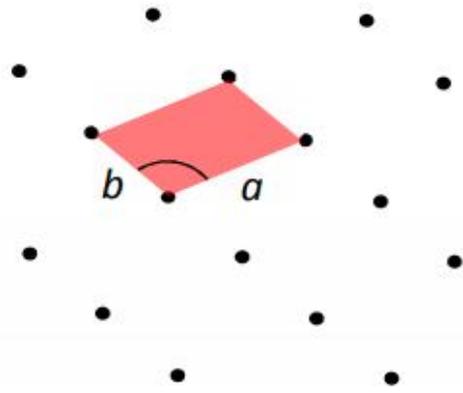
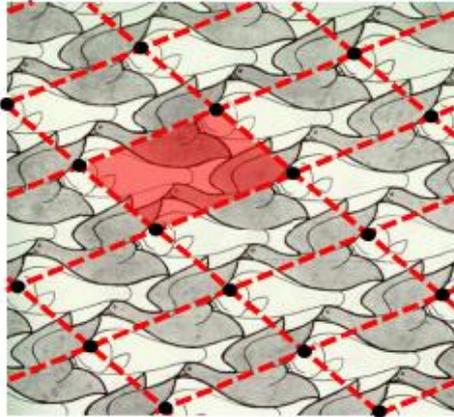
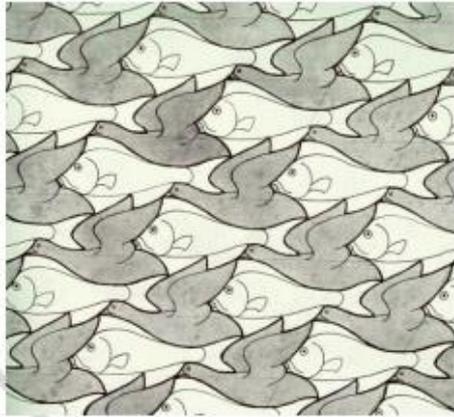
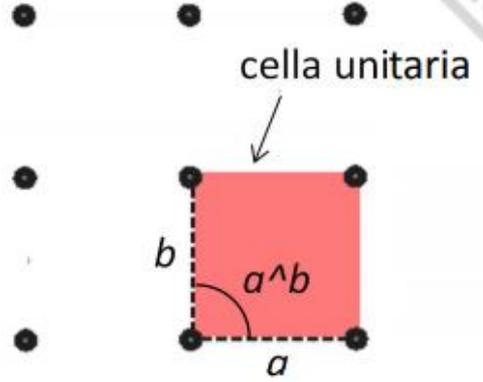
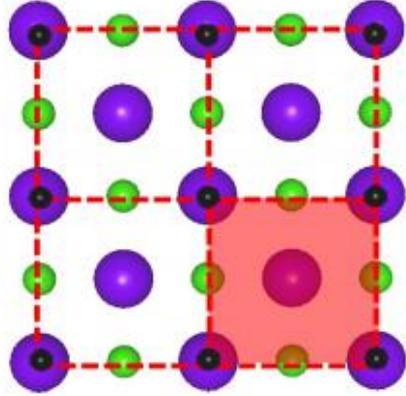
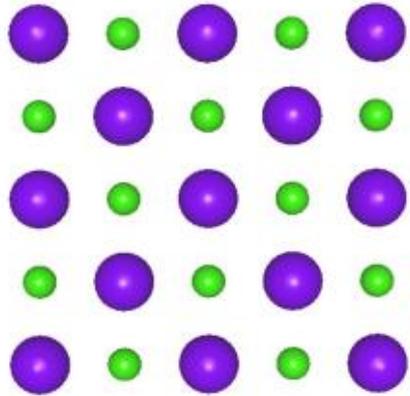


*reticolo cristallino;
insieme di punti che
esprime lo schema di
ripetizione presente
nel cristallo*

cella unitaria: rappresenta l'intero cristallo
l'intero reticolo (cristallo) può essere
ottenuto dalla cella unitaria per traslazione

descrizione microscopica: reticolo cristallino

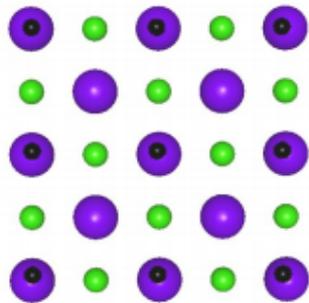
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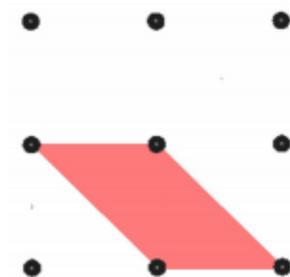
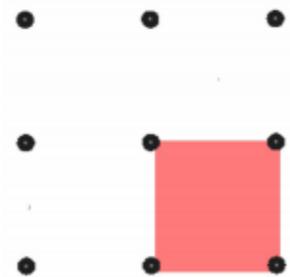
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reticolo cristallino e cella unitaria

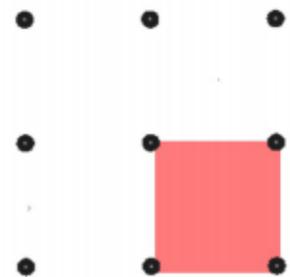
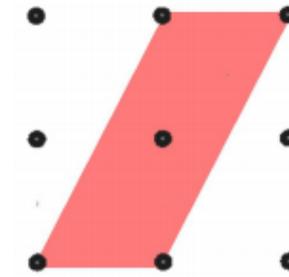
per un dato reticolo sono possibili *infinte* celle unitarie



celle "primitive"



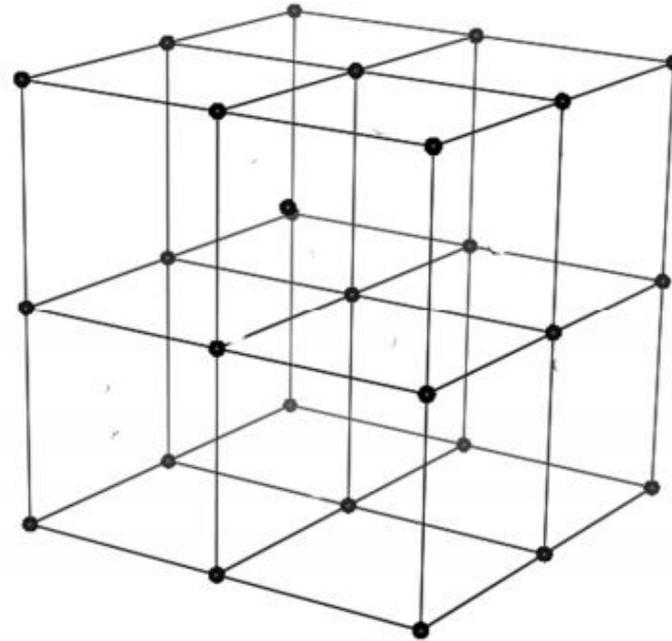
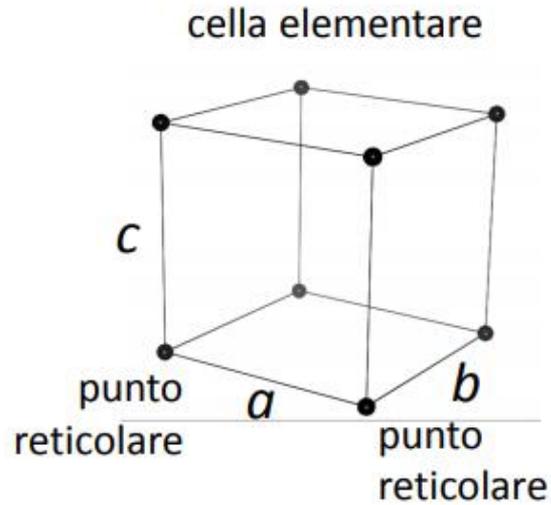
cella "non primitiva"



- si sceglie quella con
- ✓ *volume minore*
 - ✓ *stessi elementi di simmetria del reticolo*

reticolo cristallino tridimensionale

slides
delle lezioni
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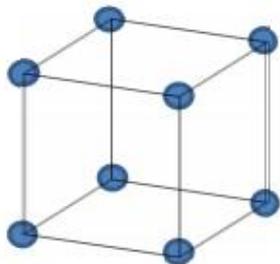
6 costanti o parametri di cella

$$(a, b, c, \alpha, \beta, \gamma)$$

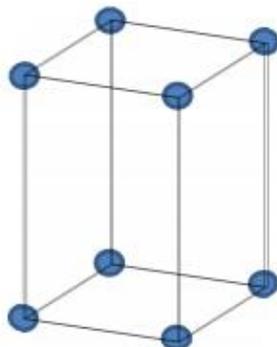
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i sette sistemi cristallini

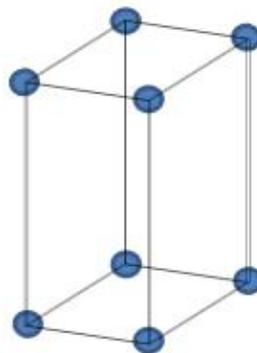
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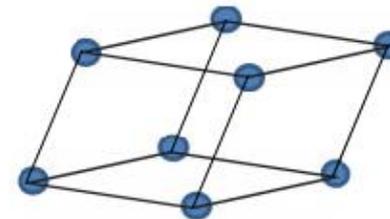
cubico
 $a = b = c$
 $\alpha = \beta = \gamma = 90^\circ$



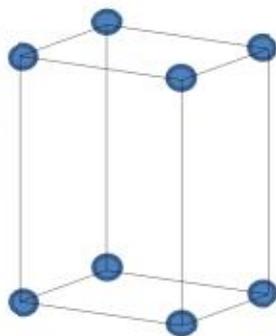
tetragonale
 $a = b \neq c$
 $\alpha = \beta = \gamma = 90^\circ$



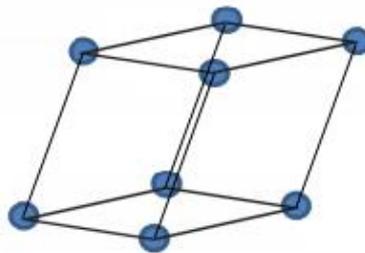
ortorombico
 $a \neq b \neq c$
 $\alpha = \beta = \gamma = 90^\circ$



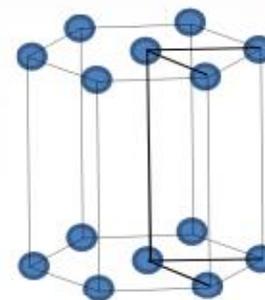
trigonale o romboedrico
 $a = b = c$
 $\alpha = \beta = \gamma \neq 90^\circ$



monoclino
 $a \neq b \neq c$
 $\alpha = \beta = 90^\circ \neq \gamma$



triclino
 $a \neq b \neq c$
 $\alpha \neq \beta \neq \gamma \neq 90^\circ$



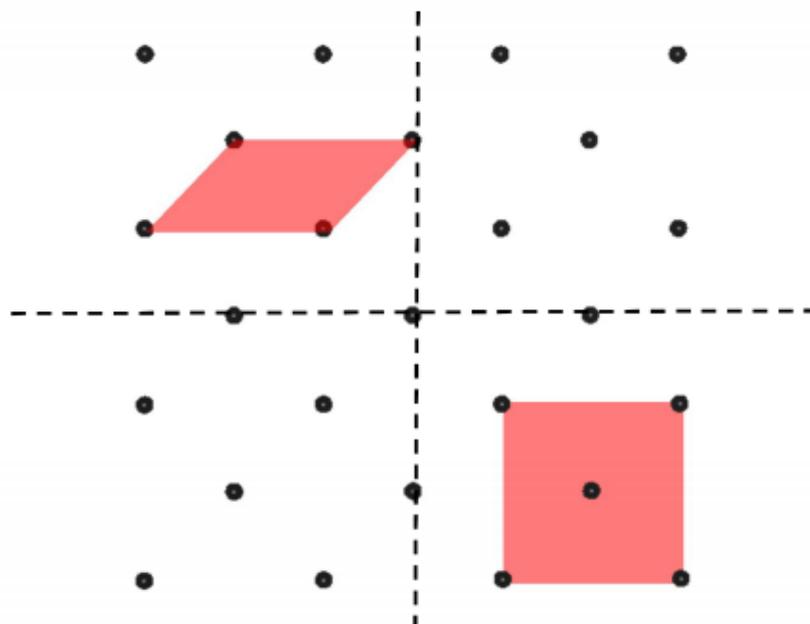
esagonale
 $a = b \neq c$
 $\alpha = \beta = 90^\circ; \gamma = 120^\circ$

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reticolo cristallino e cella unitaria

in alcuni casi la cella più piccola che soddisfa il criterio di simmetria contiene più di un punto reticolare

il reticolo ha due assi di simmetria

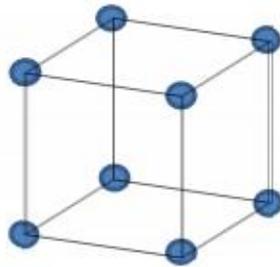


la cella non primitiva ha anche due assi di simmetria

tipi di celle unitarie non-primitive

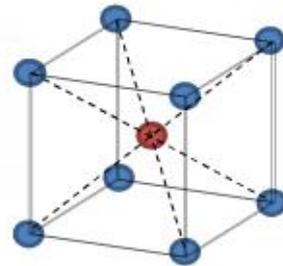
(esempio per sistema cubico)

slides
delle lezioni
A. BONIFACIO

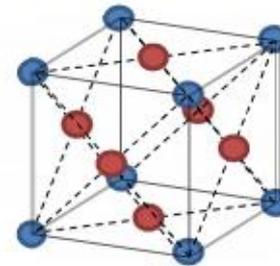


primitiva
(P)

bcc (body-centered cubic) *fcc* (face-centered cubic)



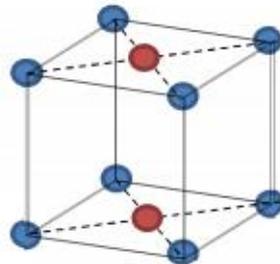
corpo centrato
(I)



a facce centrate
(F)



3 tipi di celle unitarie non-primitive

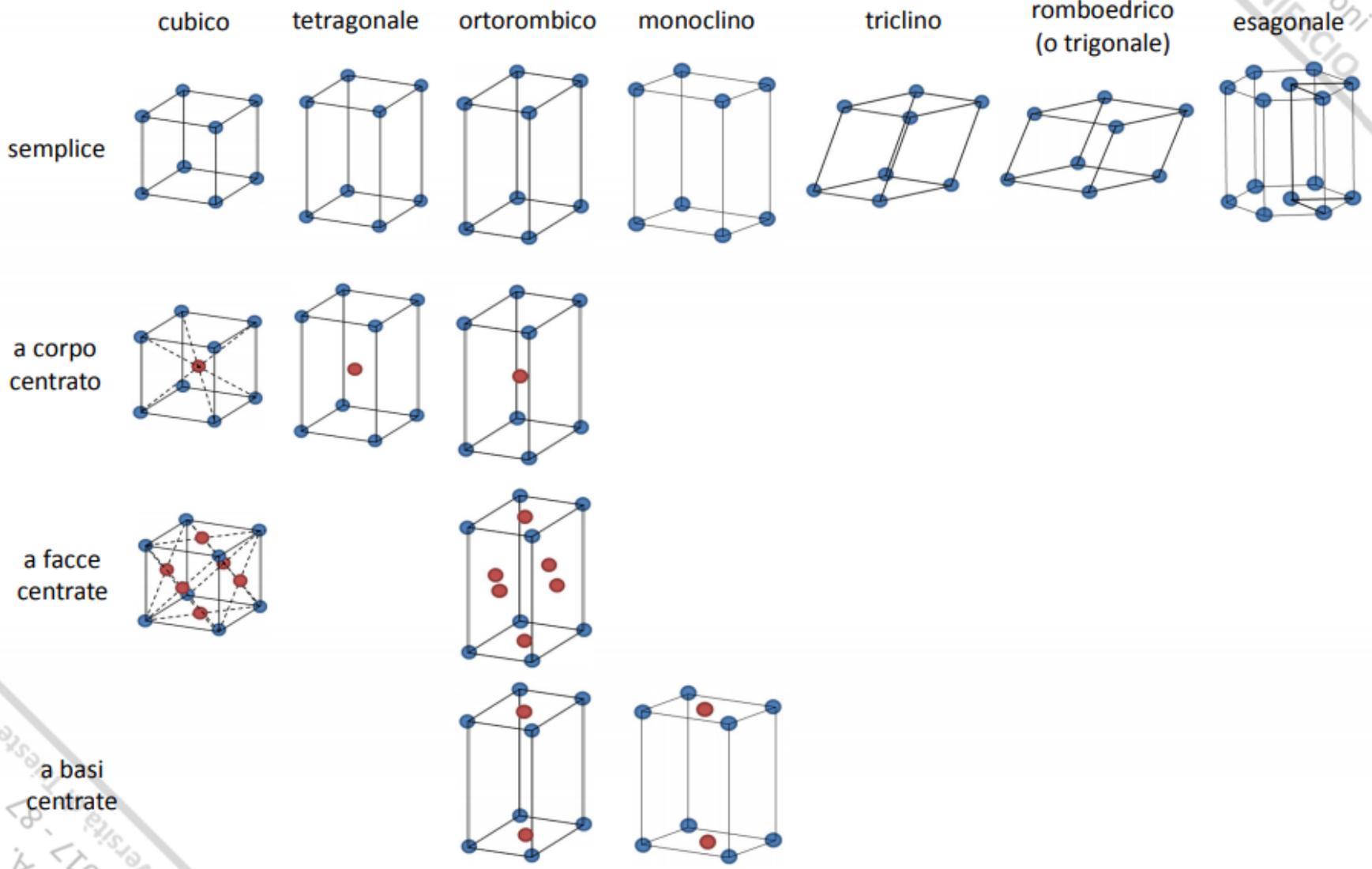


a basi centrate

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i 14 reticoli di Bravais

slides
delle lezioni
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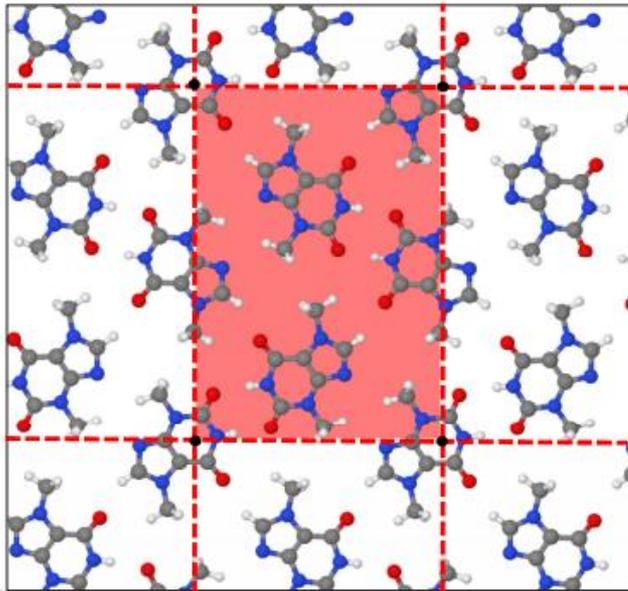


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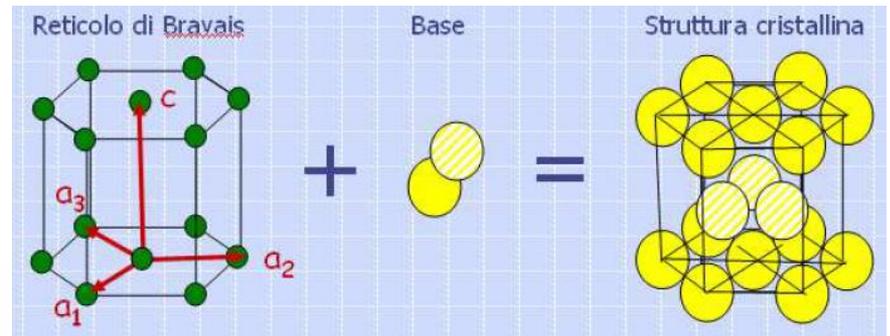
descrizione microscopica: reticolo cristallino

slides
dell'iniziativa
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i punti del reticolo non corrispondono necessariamente ad atomi, ed anche molecole asimmetriche possono dare luogo a reticoli molto regolari (es. cristalli molecolari)



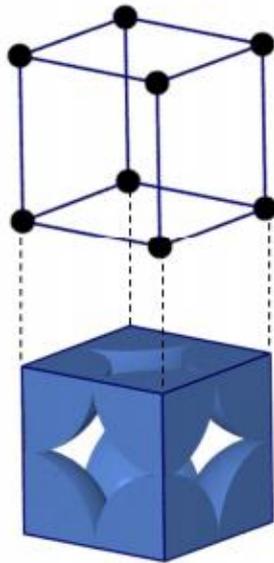
Concetto di «base» e di «struttura cristallina»



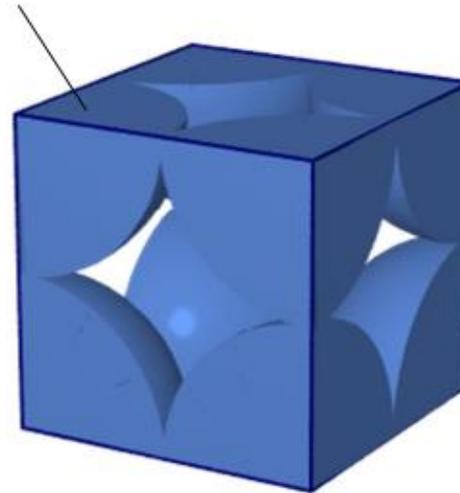
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punti reticolari e celle unitarie

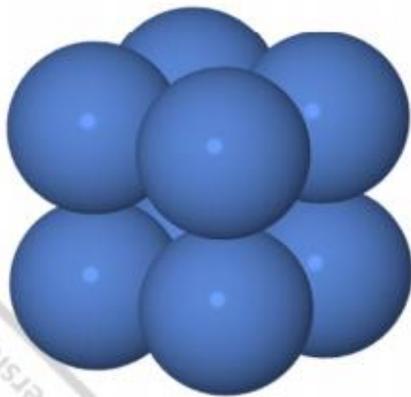
cubico primitivo



1/8 di punto
reticolare su 8 angoli

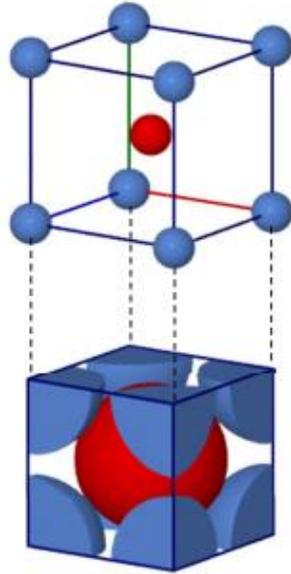


$$1/8 \times 8 = 1 \text{ punto reticolare}$$

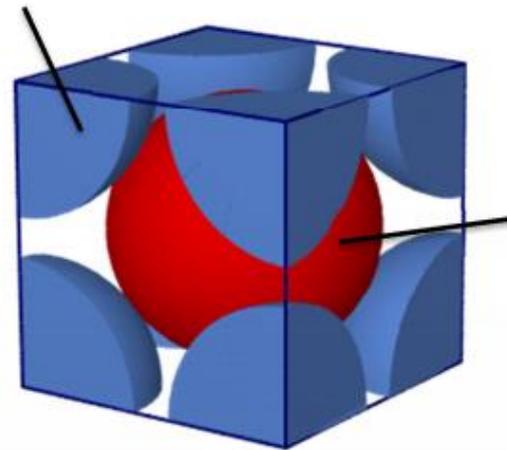


punti reticolari e celle unitarie

cubico a corpo centrato

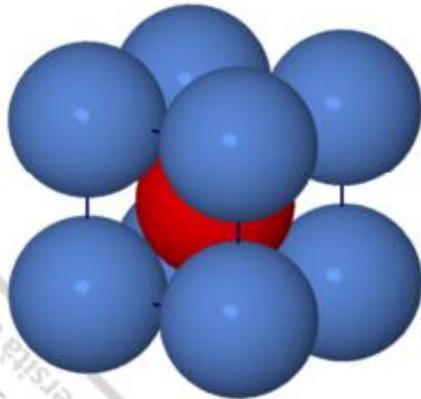


1/8 di punto
reticolare su 8 angoli



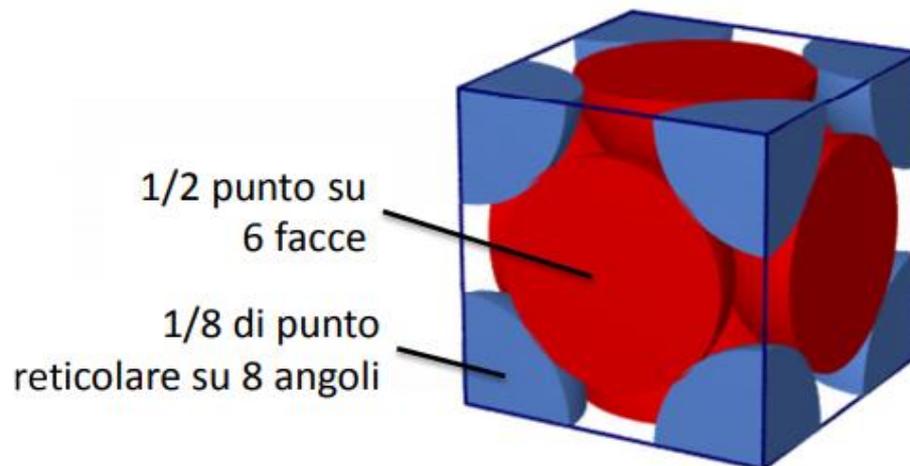
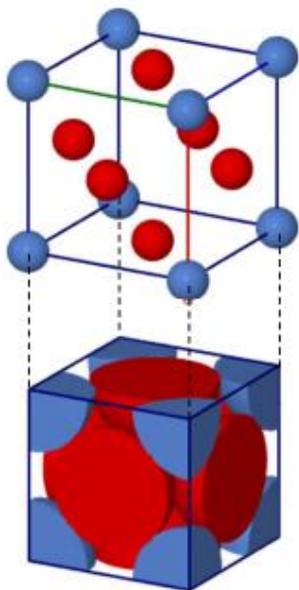
1 punto al
centro

$$(1/8 \times 8) + 1 = 2 \text{ punti reticolari}$$

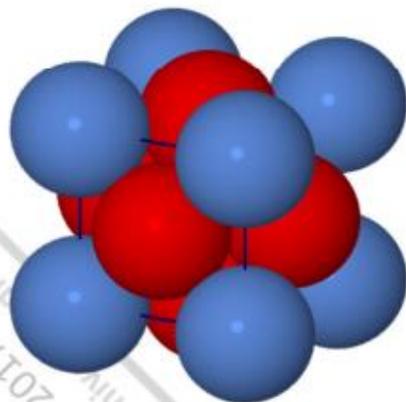


punti reticolari e celle unitarie

cubico a facce centrate



$$(1/8 \times 8) + (1/2 \times 6) = 4 \text{ punti reticolari}$$

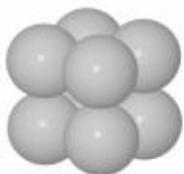


esempi di strutture cristalline: metalli

slides
delle lezioni
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*strutture semplici: ogni
punto reticolare
corrisponde ad un atomo*

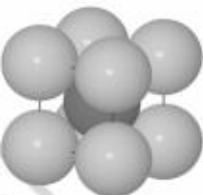
1	1A	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	2												3A	4A	5A	6A	7A	8A
	H	He												B	C	N	O	F	Ne
	Hydrogen 1.01	Helium 4.00												Boron 10.81	Carbon 12.01	Nitrogen 14.01	Oxygen 16.00	Fluorine 19.00	Neon 20.18
2	3	4																	
	Li	Be																	
	Lithium 6.94	Beryllium 9.01																	
3	11	12	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	Na	Mg											Al	Si	P	S	Cl	Ar	
	Sodium 22.99	Magnesium 24.31											Aluminum 26.98	Silicon 28.09	Phosphorus 30.97	Sulfur 32.07	Chlorine 35.45	Argon 39.95	
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
	Potassium 39.10	Calcium 40.08	Scandium 44.96	Titanium 47.87	Vanadium 50.94	Chromium 52.00	Manganese 54.94	Iron 55.85	Cobalt 58.93	Nickel 58.69	Copper 63.55	Zinc 65.39	Gallium 69.72	Germanium 72.61	Arsenic 74.92	Selenium 78.96	Bromine 79.90	Krypton 83.80	
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
	Rubidium 85.47	Strontium 87.62	Yttrium 88.91	Zirconium 91.22	Niobium 92.91	Molybdenum 95.94	Technetium (98)	Ruthenium 101.07	Rhodium 102.91	Palladium 106.42	Silver 107.87	Cadmium 112.41	Indium 114.82	Tin 118.71	Antimony 121.76	Tellurium 127.60	Iodine 126.90	Xenon 131.29	
6	55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
	Cesium 132.91	Barium 137.33	Lanthanum 138.91	Hafnium 178.49	Tantalum 180.95	Tungsten 183.84	Rhenium 186.21	Osmium 190.23	Iridium 192.22	Platinum 195.08	Gold 196.97	Mercury 200.59	Thallium 204.38	Lead 207.2	Bismuth 208.98	Polonium (209)	Astatine (210)	Radon (222)	
7	87	88	89	104	105	106	107	108	109										
	Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt										
	Francium (223)	Radium (226)	Actinium (227)	Rutherfordium (261)	Dubnium (262)	Seaborgium (266)	Bohrium (264)	Hassium (269)	Mendelevium (268)										



Cubico
primitivo



Cubico a facce centrate
(cubico compatto)



Cubico a corpo
centrato



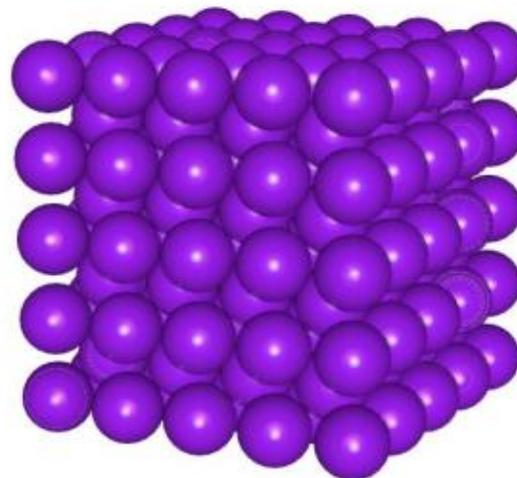
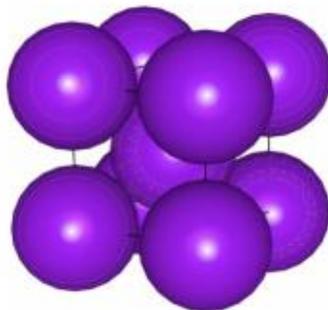
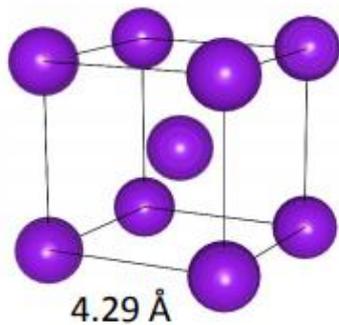
Esagonale
compatto

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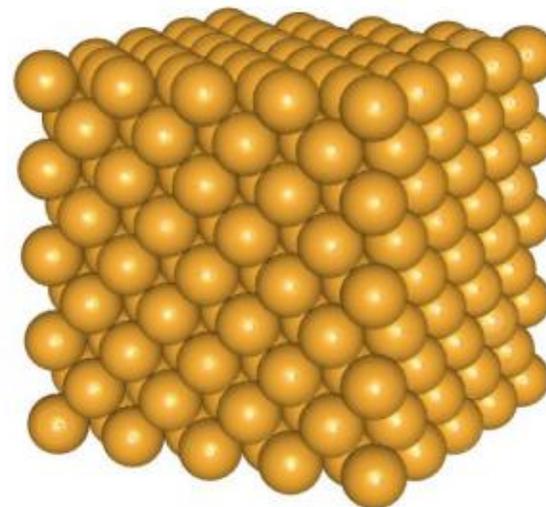
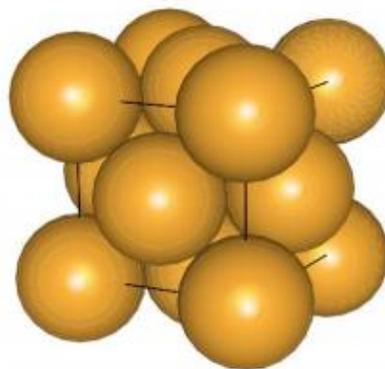
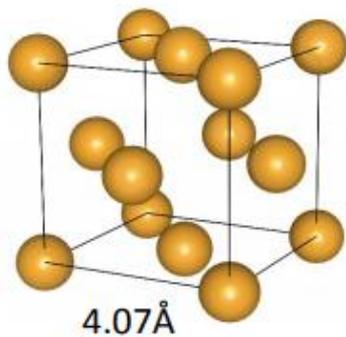
esempi *bcc* e *fcc*: metalli

slides
delle lezioni
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Na



Au

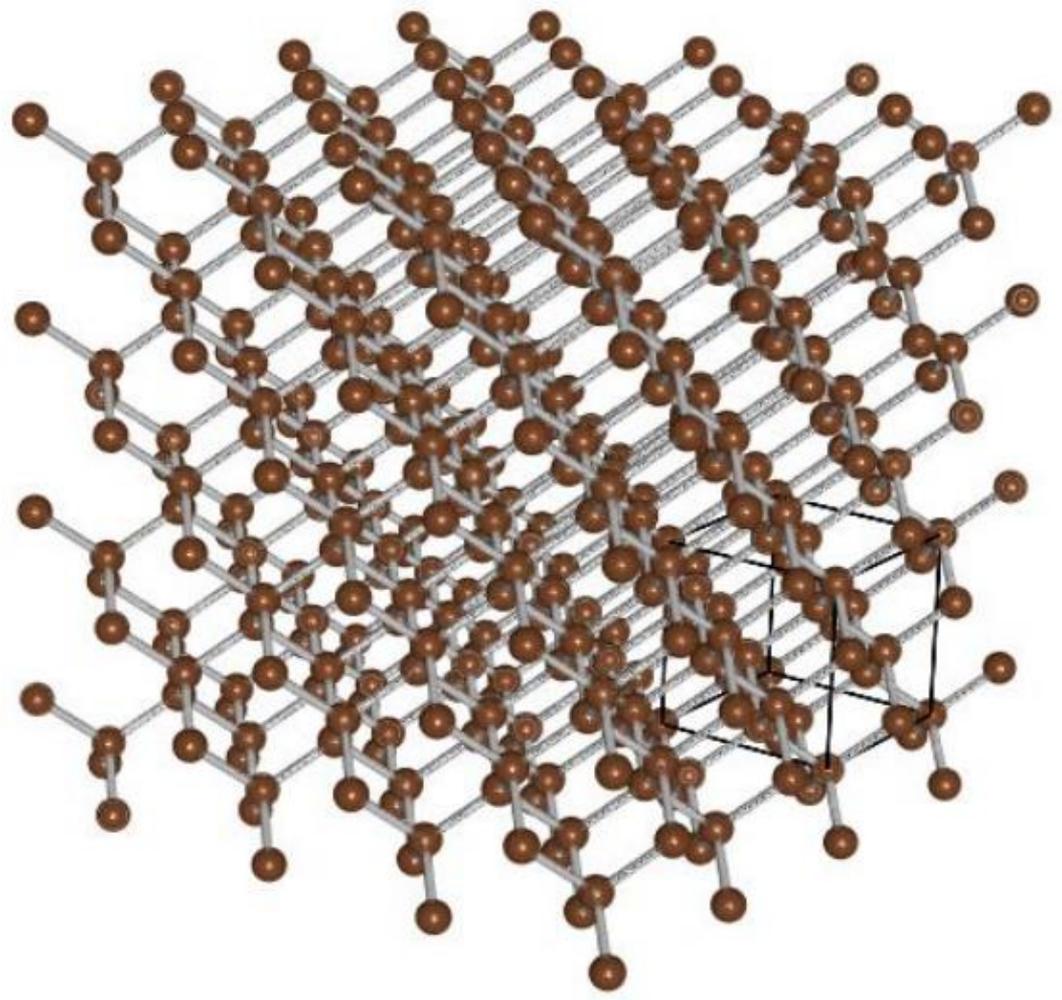
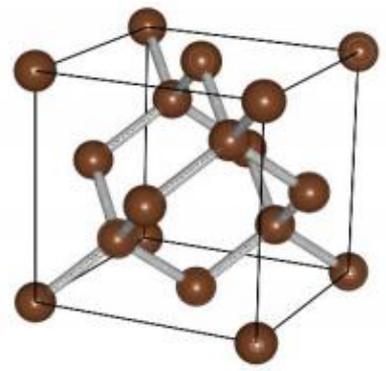


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esempi cristalli altri elementi

slides
delle lezioni
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C
(diamante)

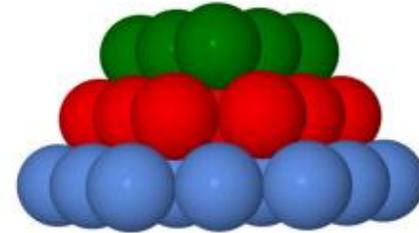
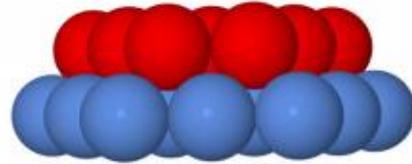
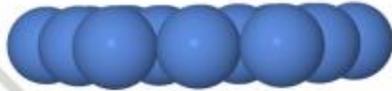
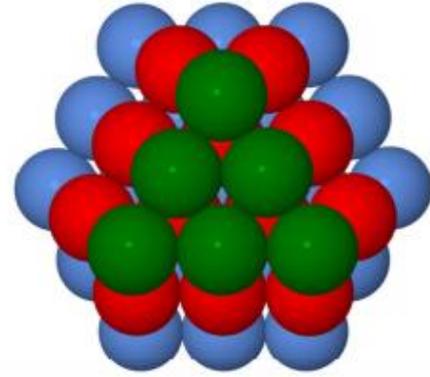
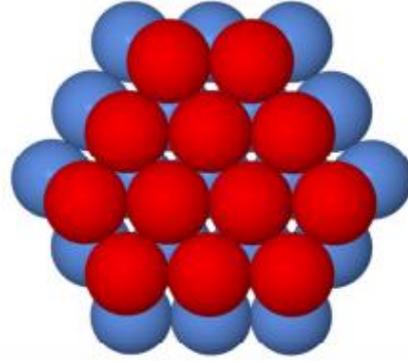
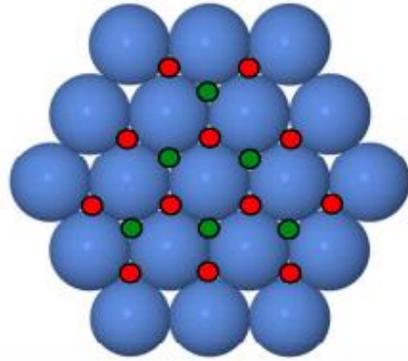


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impaccamento nelle strutture cristalline

cubico compatto

slides
delle lezioni
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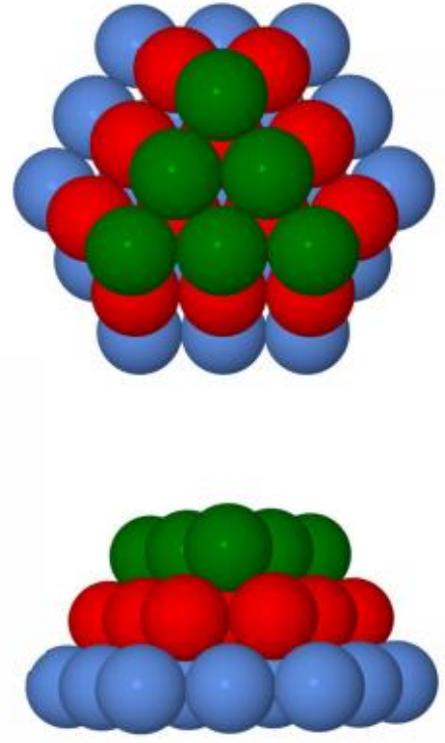
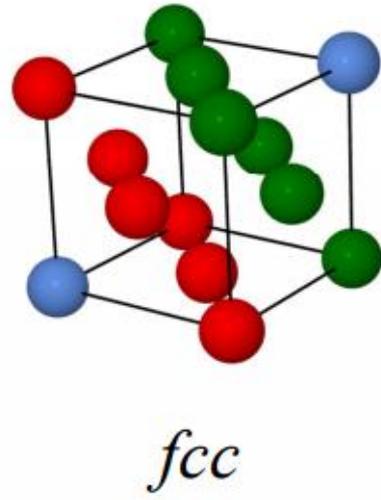
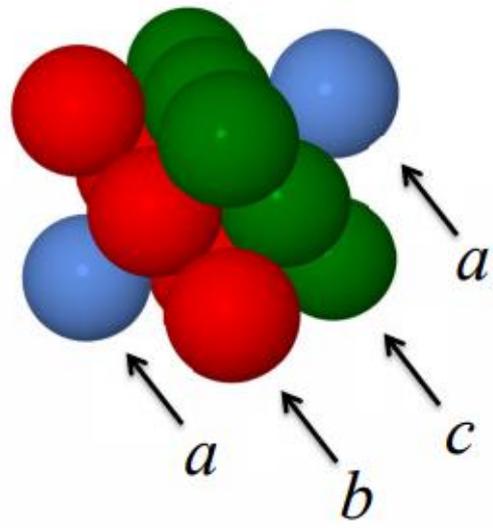
c
b
a

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slides
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cubico compatto

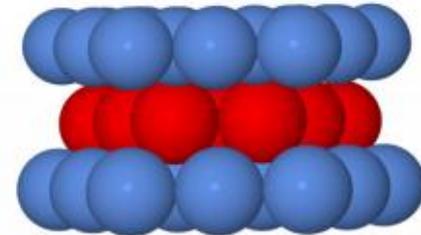
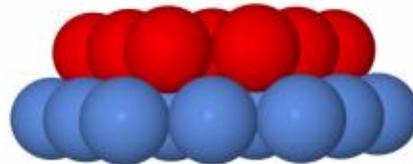
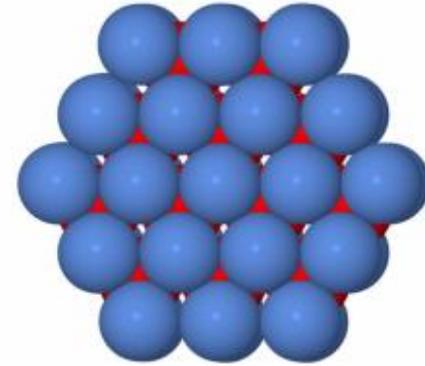
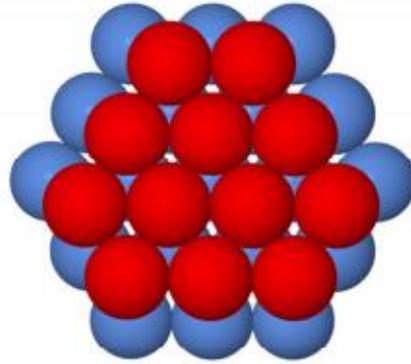
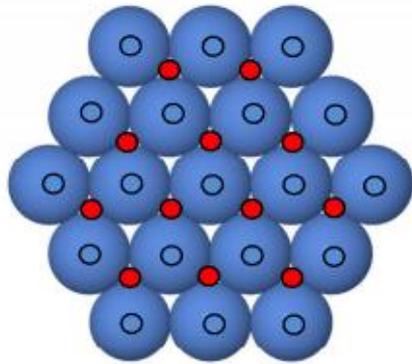


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impaccamento nelle strutture cristalline

esagonale compatto

slides
delle lezioni
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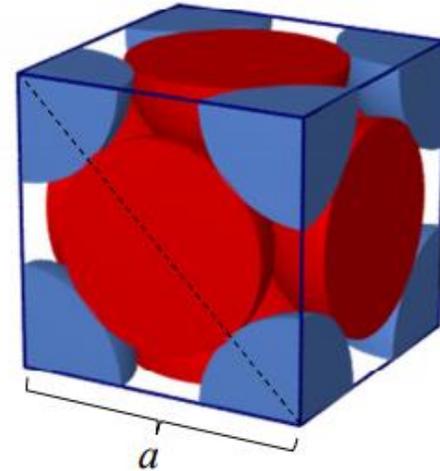
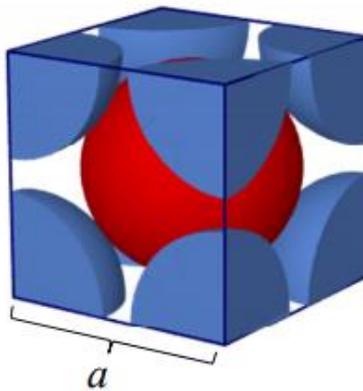
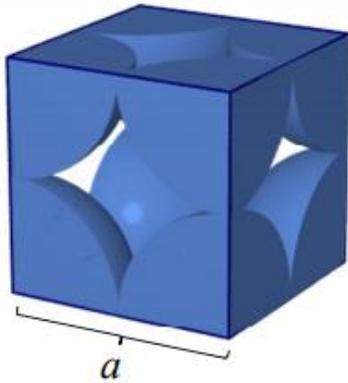
a
b
a

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coefficienti di impaccamento

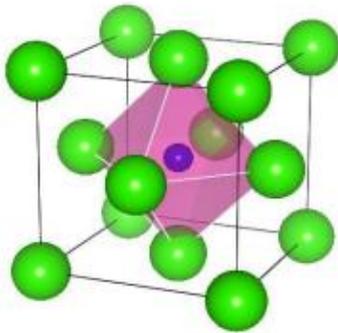
volume atomo raggio $r = 4/3 \pi r^3$
volume cella cubica di lato $a = a^3$

coefficiente di impaccamento = $\frac{\text{volume occupato da atomi}}{\text{volume cella}}$

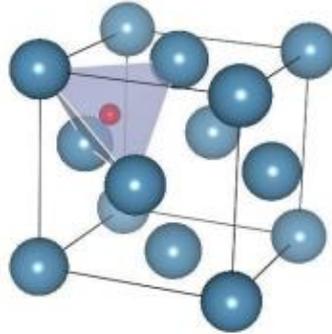


siti interstiziali nella *fcc*

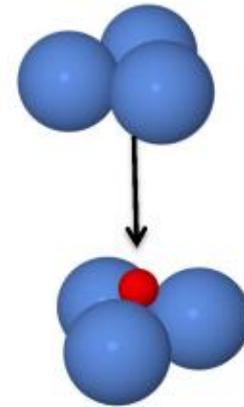
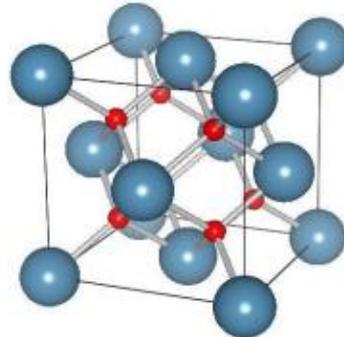
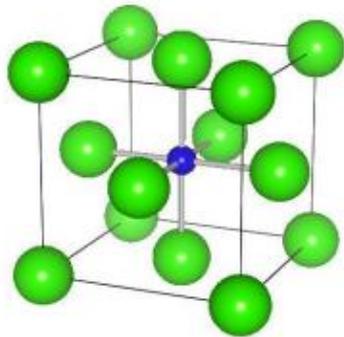
sito
ottaedrico



sito
tetraedrico



*spazi (interstizi) tra gli
atomi coincidenti con i
punti reticolari*



*esempio sito
ottaedrico*

4 siti

ottaedrici*

$$r'/r = 0.414$$

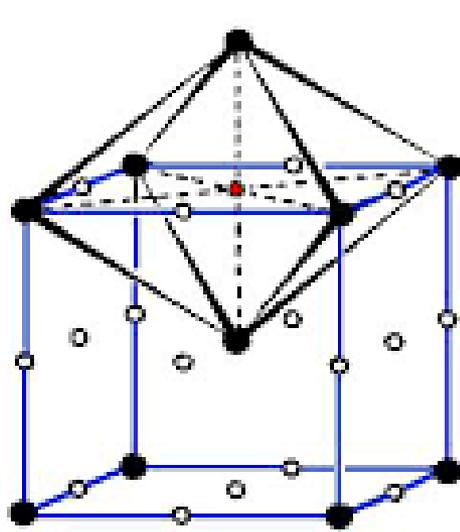
8 siti

tetraedrici

$$r'/r = 0.225$$

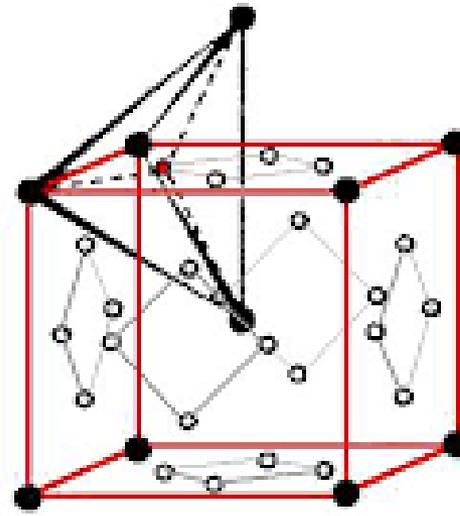
* 1 al centro + ¼ di sito per ogni "spigolo" della cella (12)

siti interstiziali nella bcc



Octahedral Site

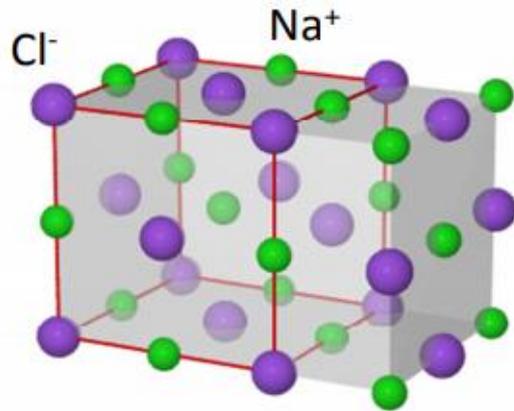
6 siti ottaedrici
 $r'/r = 0.154$



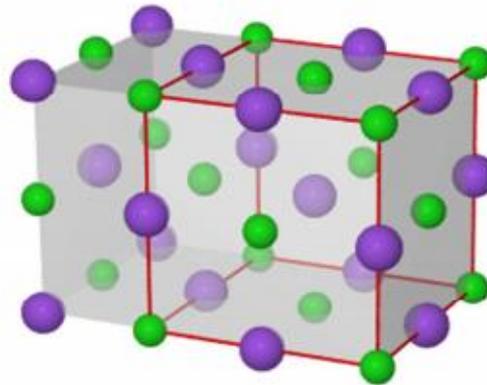
Tetrahedral Site

12 siti tetraedrici
 $r'/r = 0.291$

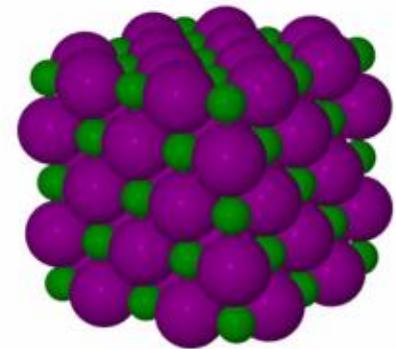
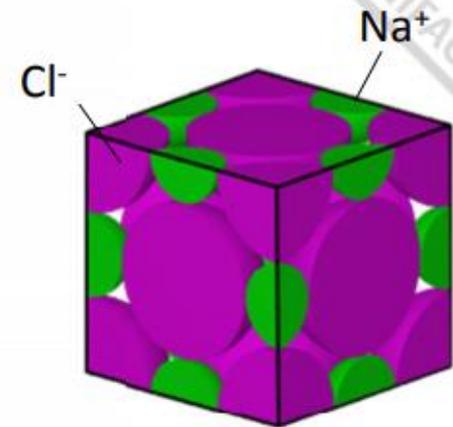
cristalli ionici(1): struttura del NaCl (salgemma)



reticolo fcc di Cl^- in cui i siti ottaedrici sono occupati da Na^+



reticolo fcc di Na^+ in cui i siti ottaedrici sono occupati da Cl^-



hanno la stessa struttura cristallina:

- MX alogenuri dei metalli alcalini (gruppo I)
(es. KCl , LiF , KBr , ...)
- MO, MS ossidi e solfuri dei metalli alcalino-terrosi (gruppo II)
(es. CaO , MgO , BaO , MgS , ...)

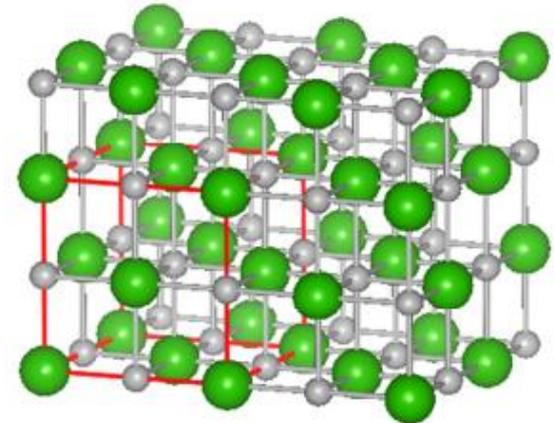
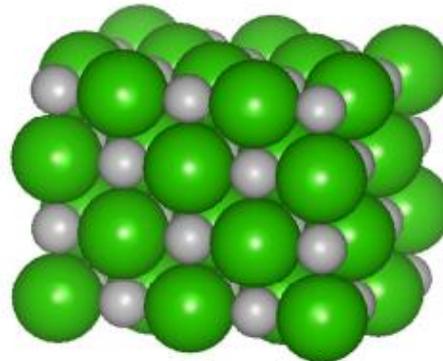
cristalli ionici(2): struttura del CsCl

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struttura NaCl

reticolo fcc di anioni in cui i siti ottaedrici sono occupati da cationi

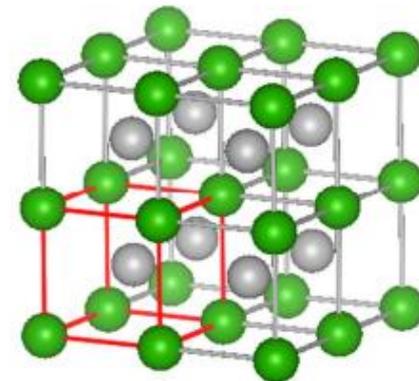
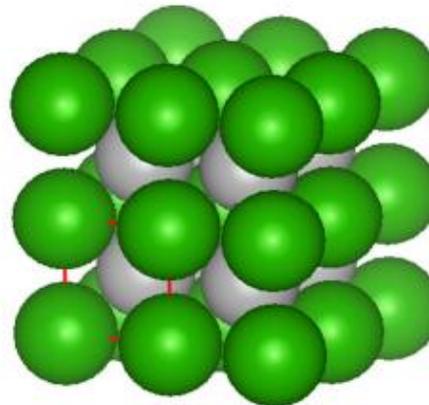
$$0.414 < \frac{\text{raggio cationi}}{\text{raggio anioni}} < 0.732$$



struttura CsCl

2 reticoli di celle cubiche primitive compenetrati

$$0.732 < \frac{\text{raggio cationi}}{\text{raggio anioni}}$$



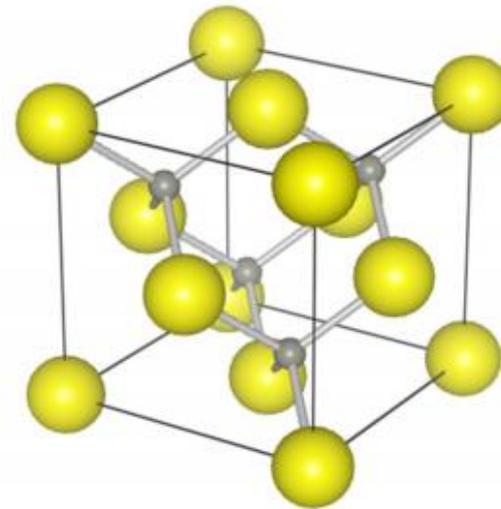
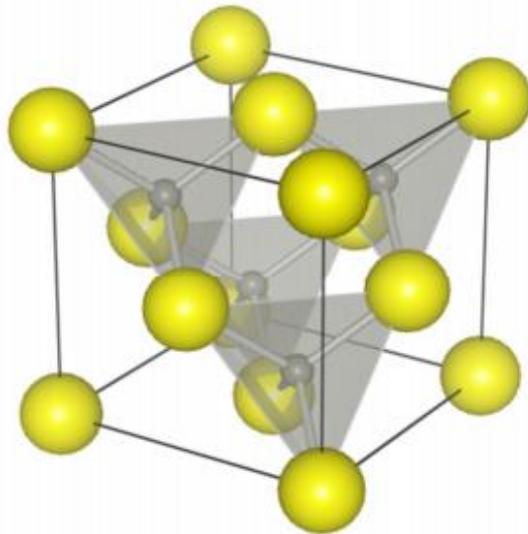
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cristalli ionici(3): struttura del ZnS

$$\frac{\text{raggio cationi}}{\text{raggio anioni}} < 0.414$$

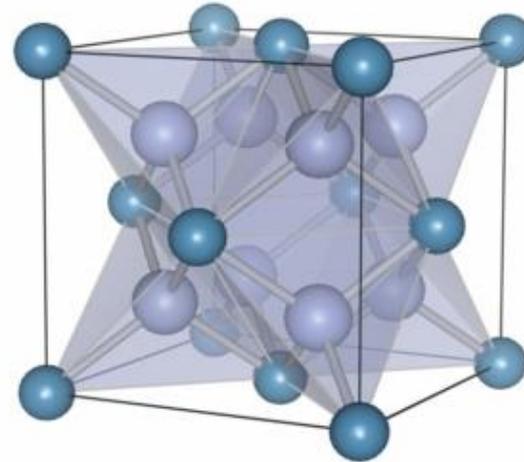
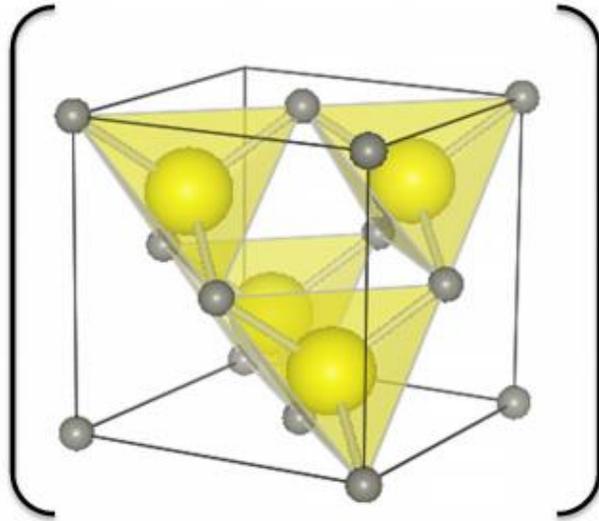
struttura ZnS
(blenda cubica o sfalerite)

*reticolo fcc di anioni S^{2-} in cui
metà dei siti tetraedrici sono
occupati da cationi Zn^{2+}*



cristalli ionici(4): struttura del CaF_2

slides
delle lezioni
A. BONIFACIO



cella fcc

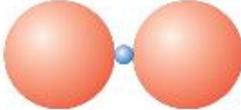
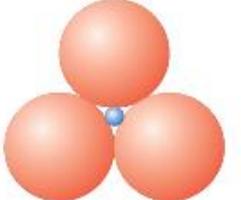
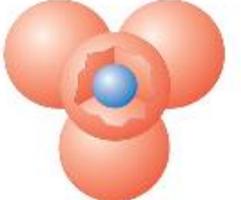
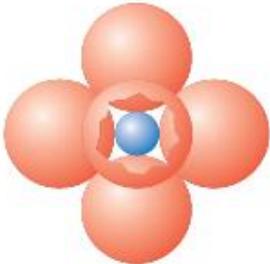
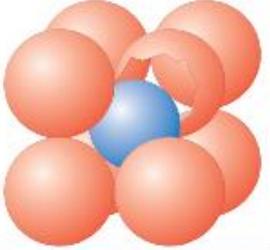
8 siti tetraedrici
4 punt reticolari

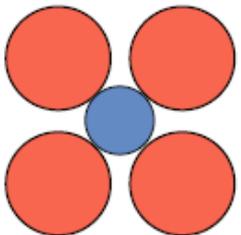


struttura CaF_2
(fluorite)

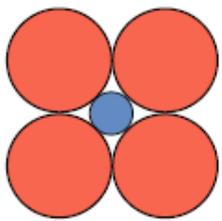
*reticolo fcc di cationi Ca^{2+} in cui
TUTTI i siti tetraedrici sono
occupati da anioni F^-*

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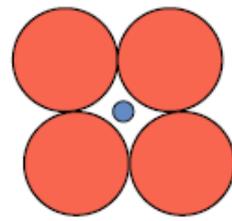
<i>Coordination Number</i>	<i>Cation–Anion Radius Ratio</i>	<i>Coordination Geometry</i>
2	<0.155	
3	0.155–0.225	
4	0.225–0.414	
6	0.414–0.732	
8	0.732–1.0	



Stable

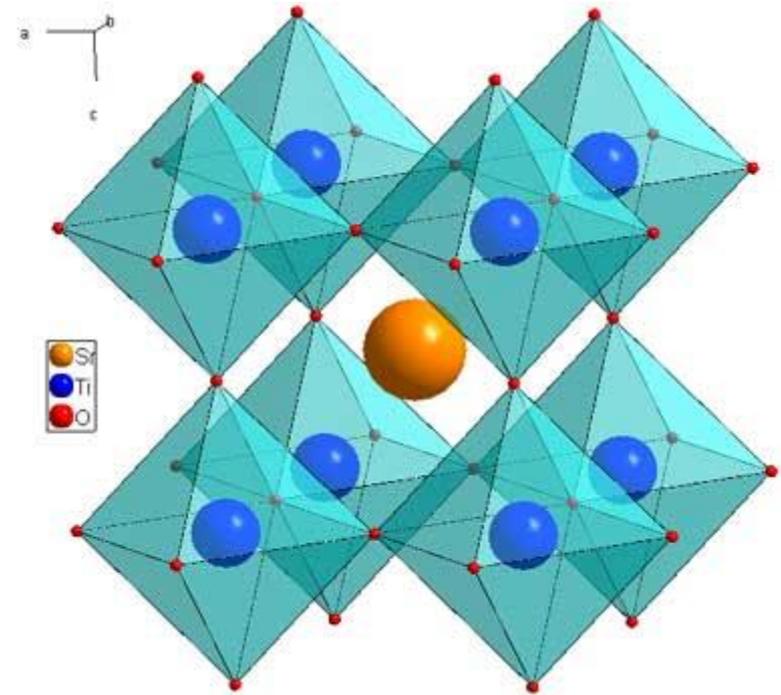
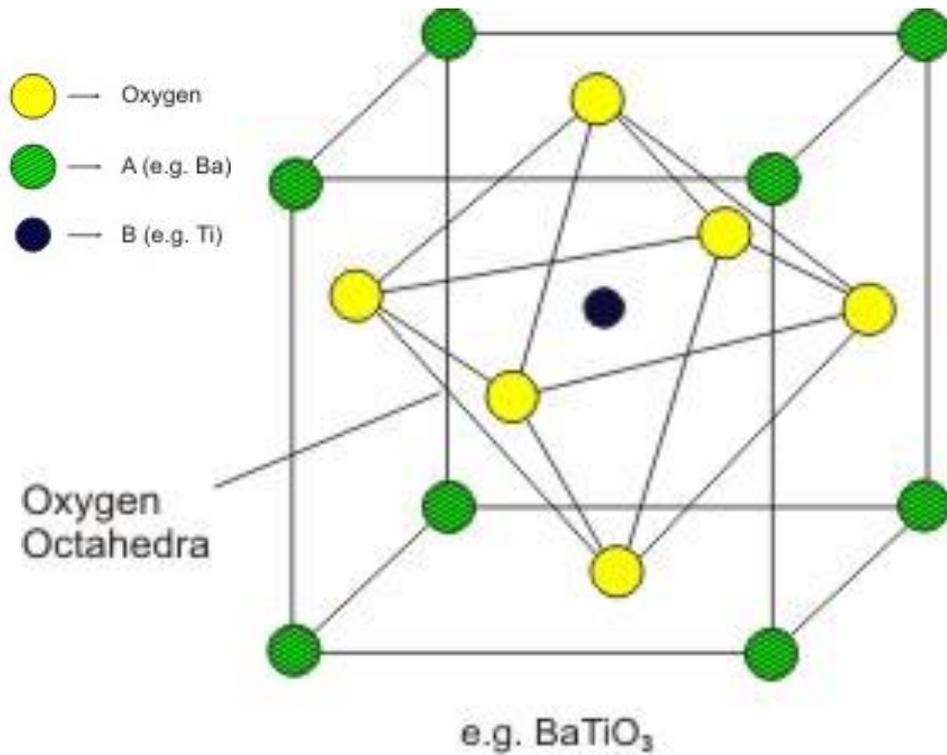


Stable



Unstable

Perovskite



Perovskite: Superconduttori

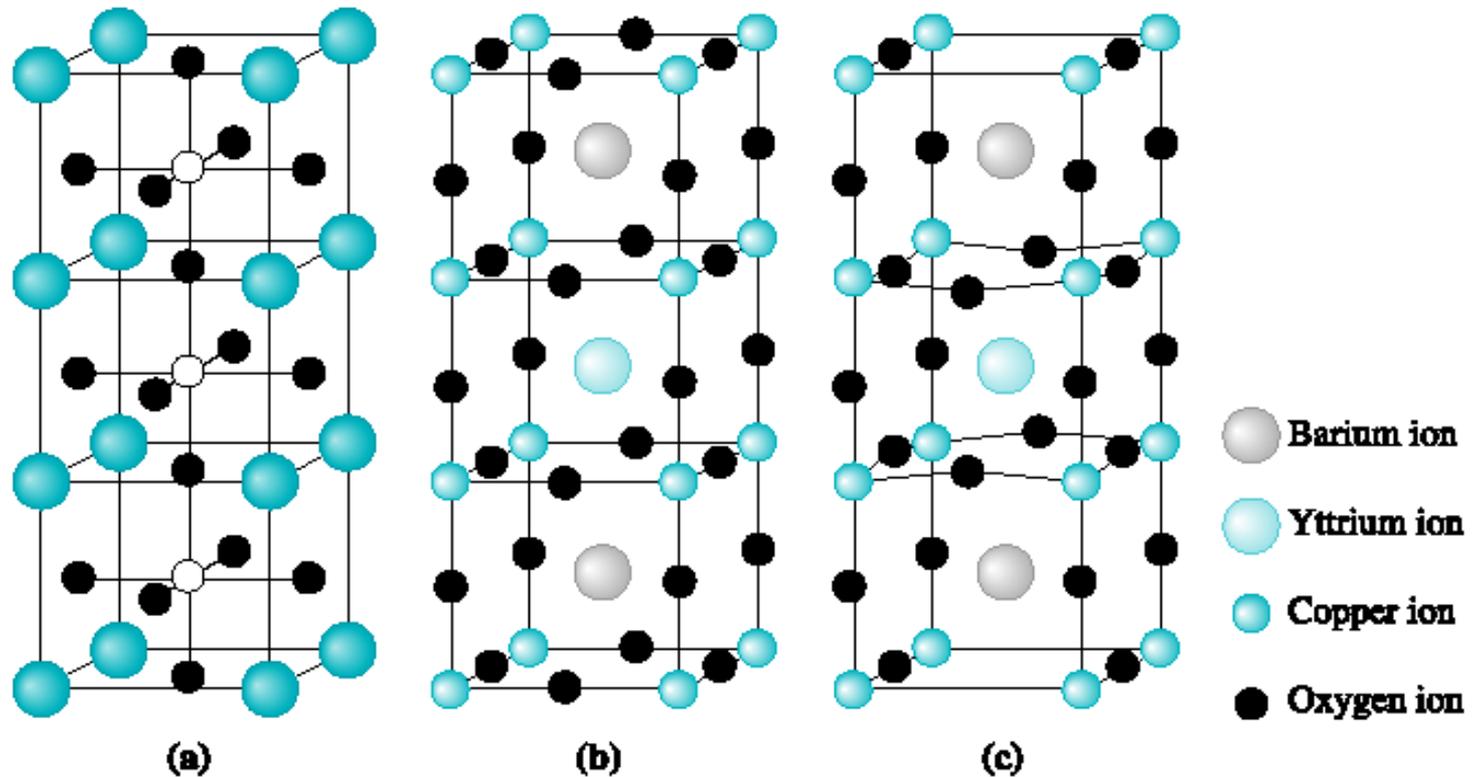
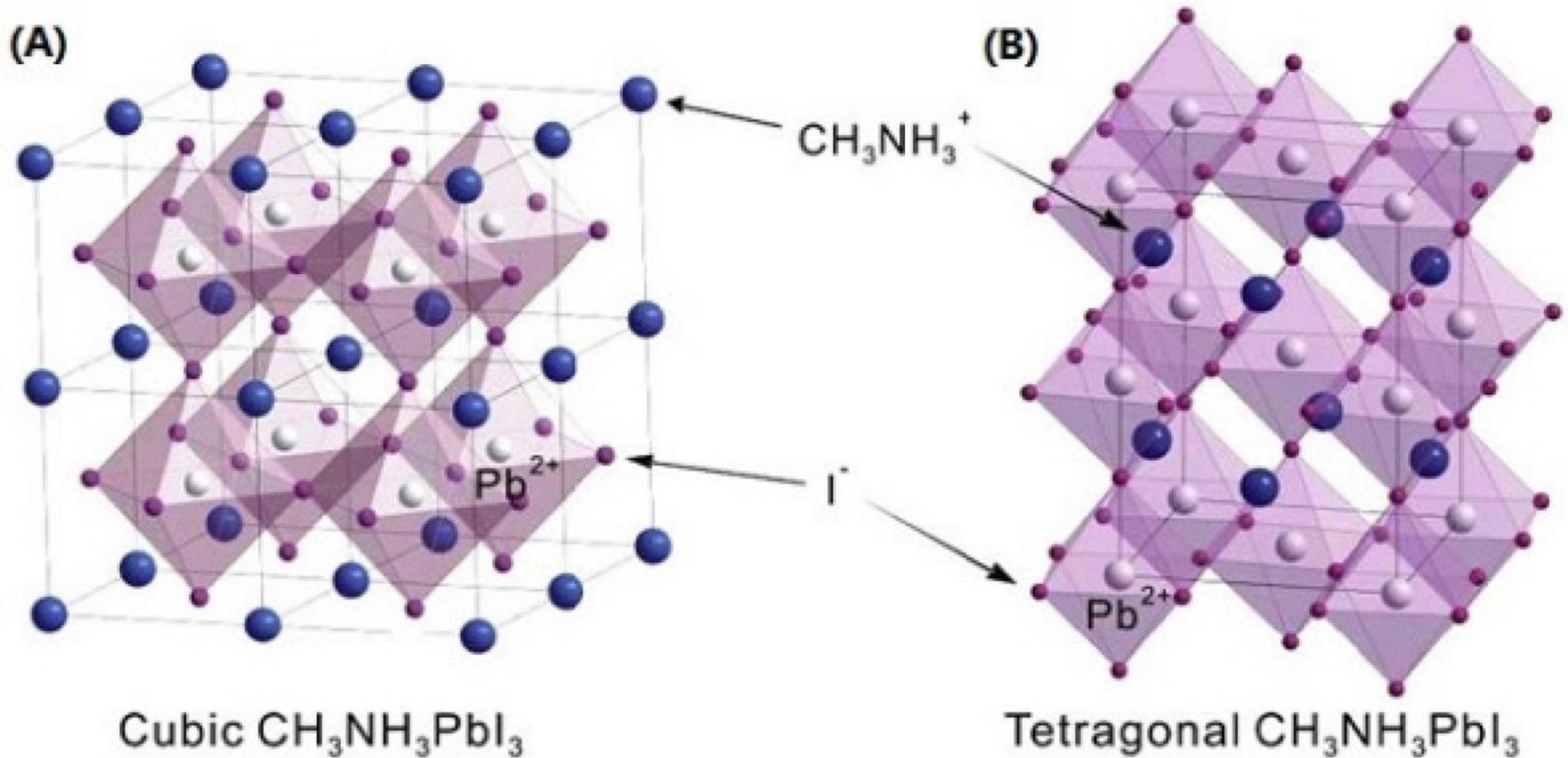


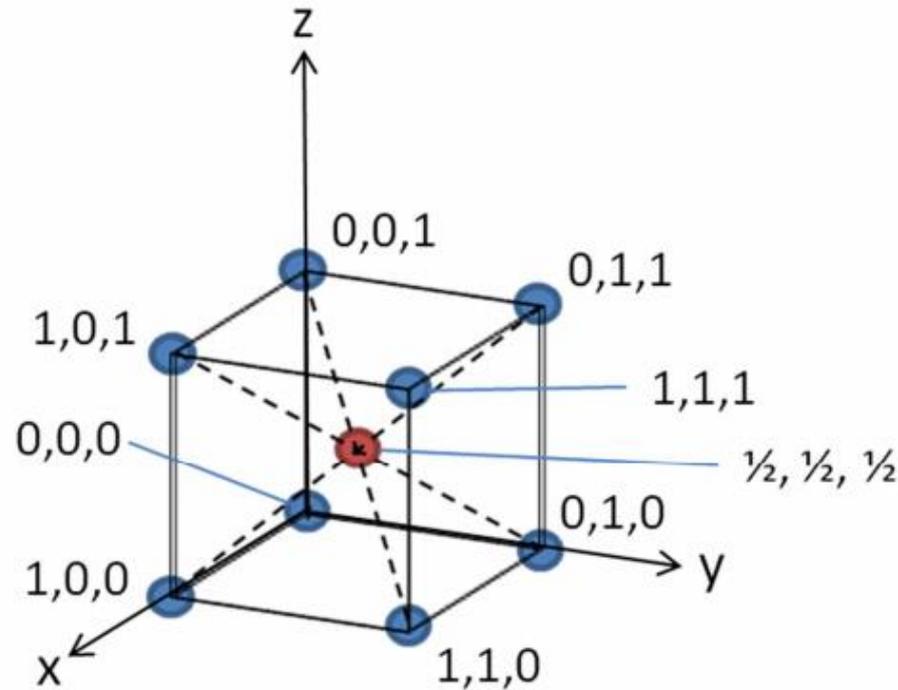
Figure 3.36 Crystal structure of a new high T_c ceramic superconductor based on a yttrium barium copper oxide. These materials are unusual in that they are ceramics, yet at low temperatures their electrical resistance vanishes. (Source: ill.fr/dif/3D-crystals/superconductor.html; © M. Hewat 1998.)

Perovskite Ibrida

- forse una rivoluzione nel fotovoltaico? -

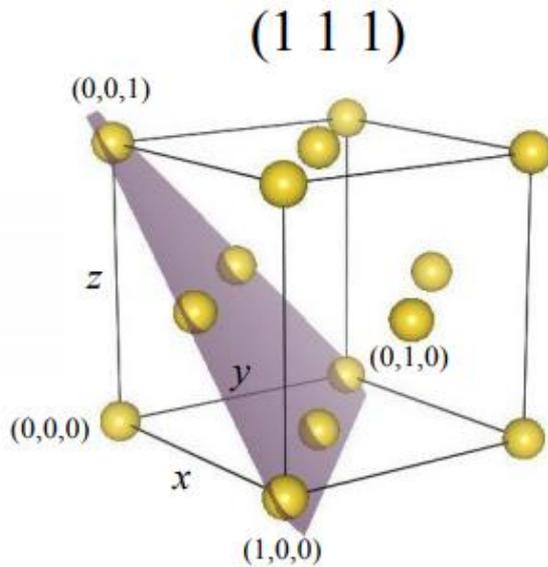


coordinate frazionarie



*definiscono la posizione di un atomo
o di un punto reticolare all'interno
della cella cristallina*

indici di Miller



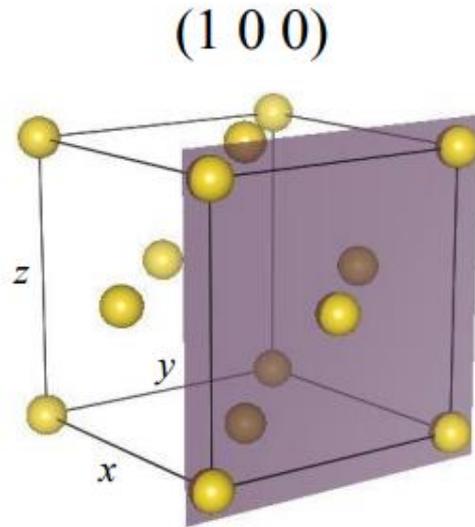
(hkl) identificano una famiglia di piani cristallini in un reticolo di Bravais

terna di reciproci delle intercette del piano in coordinate frazionarie

<i>intercette</i>	<i>x</i>	<i>y</i>	<i>z</i>
	1	1	1
<i>reciproco</i>	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{1}$
<i>indici</i>	1	1	1

$$\left(\overbrace{\frac{1}{\text{intercetta } x}}^h \quad \overbrace{\frac{1}{\text{intercetta } y}}^k \quad \overbrace{\frac{1}{\text{intercetta } z}}^l \right)$$

indici di Miller



(hkl) identificano una famiglia di piani cristallini in un reticolo di Bravais

terna di reciproci delle intercette del piano in coordinate frazionarie

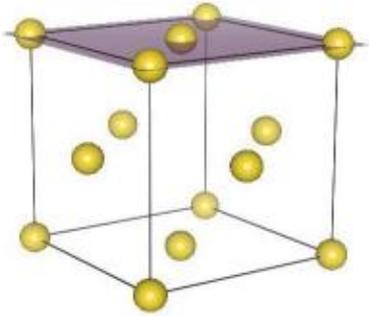
<i>intercette</i>	<i>x</i>	<i>y</i>	<i>z</i>
	1	∞	∞
<i>reciproco</i>	$\frac{1}{1}$	$\frac{1}{\infty}$	$\frac{1}{\infty}$
<i>indici</i>	1	0	0

$$\left(\overbrace{\frac{1}{\text{intercetta } x}}^h \quad \overbrace{\frac{1}{\text{intercetta } y}}^k \quad \overbrace{\frac{1}{\text{intercetta } z}}^l \right)$$

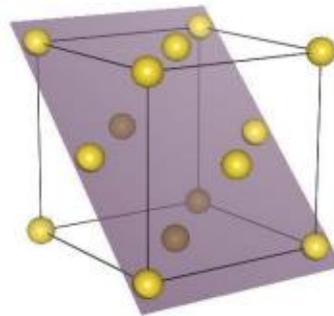
indici di Miller

slides
delle lezioni
A. BONIFACIO

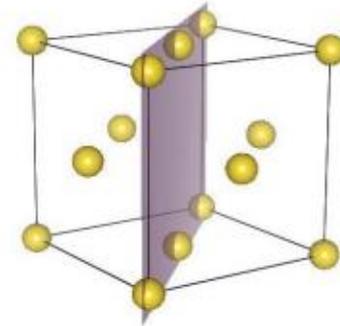
(001)



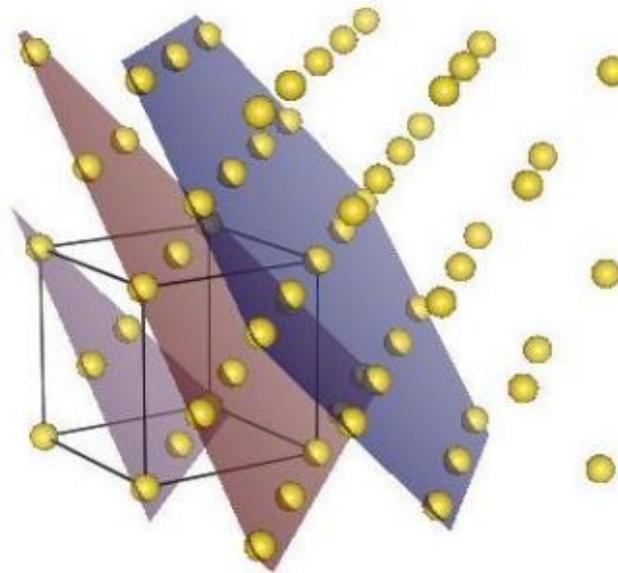
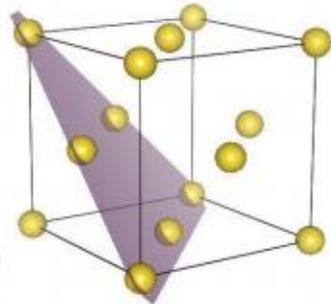
(101)



(110)



(111)

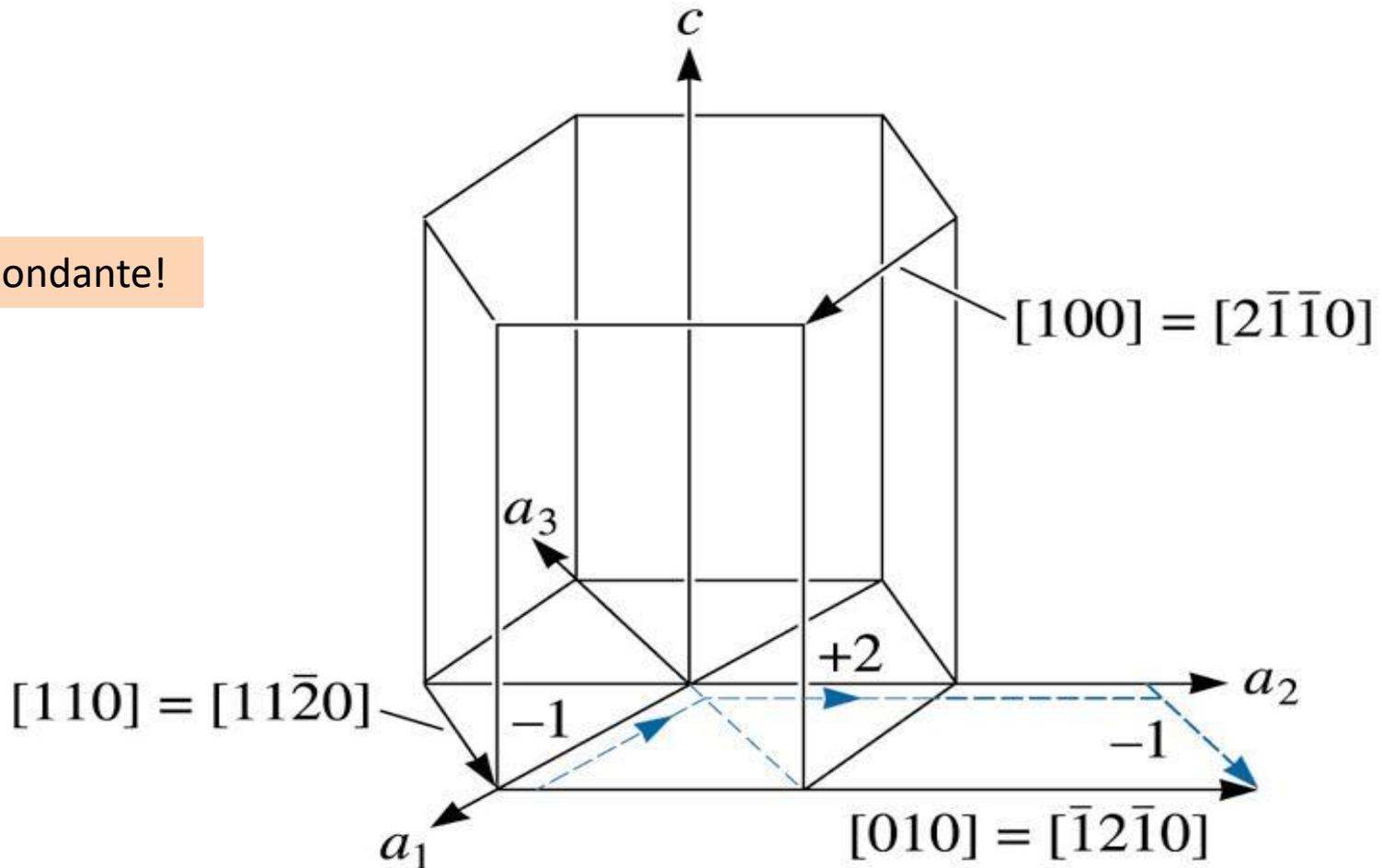


*(hkl) identifica
una famiglia di
piani paralleli*

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Notazione per sistemi esagonali

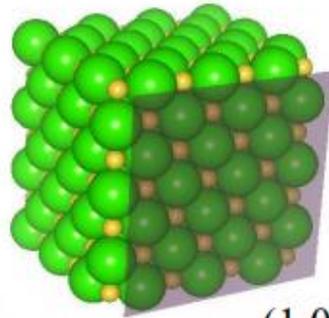
Ridondante!



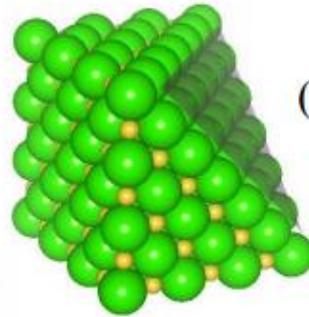
Nomenclatura Indici di Miller

- [hkl] → la direzione che passa per l'origine e il punto (h,k,l)
- <hkl> → la famiglia di direzioni equivalenti (es: nel sistema cubico [hkl], [klh], [lkh],...)
- (hkl) → il piano che intercetta gli assi a $1/h$, $1/k$, $1/l$, e la famiglia di piani ad esso paralleli, distanziati tra loro di $d_{(hkl)}$
- {hkl} → famiglia di piani equivalenti (es: nel sistema cubico (hkl), (klh), (lkh),...)
- <hkl>{hkl} → serie di coppie direzione-piano, in cui la direzione appartiene al piano
- Per indicare il segno meno talvolta si utilizza un segno sopra l'indice. Es: ($h\bar{k}l$) equivale a (h-kl)

piani cristallografici: esempio NaCl



(1 0 0)

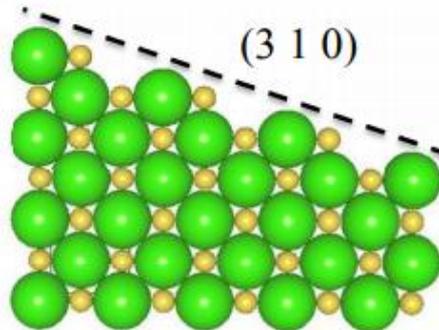
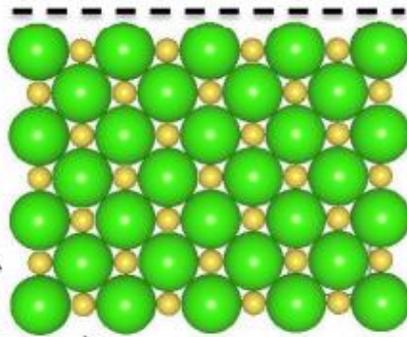


(1 1 1)

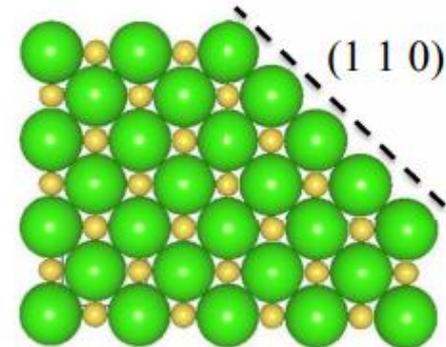
*diversi piani
cristallini hanno
"densità" diverse*

*→ proprietà chimiche e
fisiche diverse a seconda
della faccia del cristallo*

(0 1 0)



(3 1 0)



(1 1 0)

Leghe metalliche

materiali composti da due o più elementi chimici, uno dei quali è presente in percentuale più alta ed è un metallo

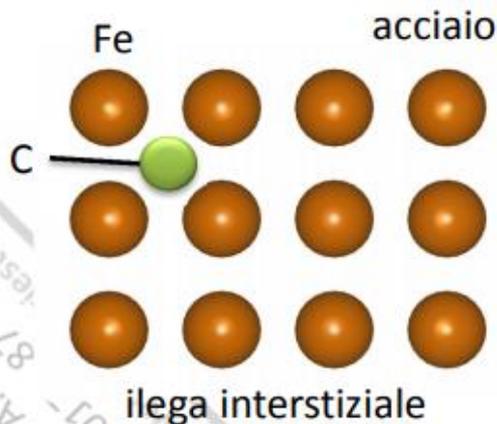
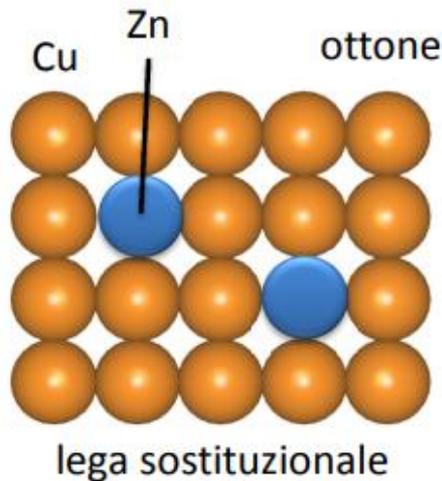
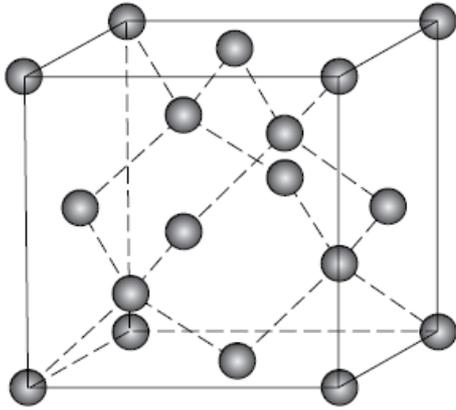


TABELLA 13.4 Leghe e loro usi

Nome	Composizione comune (massa %)	Usi
<i>Sostituzionale</i>		
Ottone	90 Cu : 10 Zn	Decorazioni
Peltro	85 Sn : 7 Cu : 6 Bi : 2 Sb	Piatti, bigiotteria, figurine
Bronzo	92–97 Cu : 1–8 Sn : 0–2 Zn	Medaglie, statue
Oro 14 carati	58 Au : 30 Ag : 12 Cu	Gioielli
Argento sterling	92.5 Ag : 7.5 Cu	Gioielli, utensili da cucina
Argento da conio	90 Ag : 10 Cu	Monete d'argento
Piombo per saldature	67 Pb : 33 Sn	Tubi saldati
<i>Interstiziale</i>		
Acciaio	98–99.9 Fe : 0–2 C	Materiali per costruzione
Acciaio inossidabile	>10.5 Cr : <89.5 Fe	Utensili da cucina, materiali strutturali

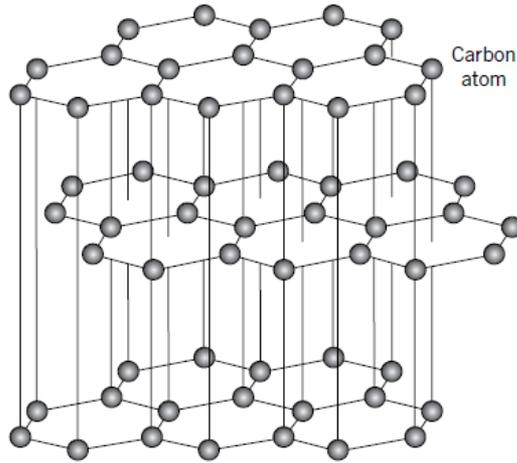
Strutture del Carbonio

Diamante

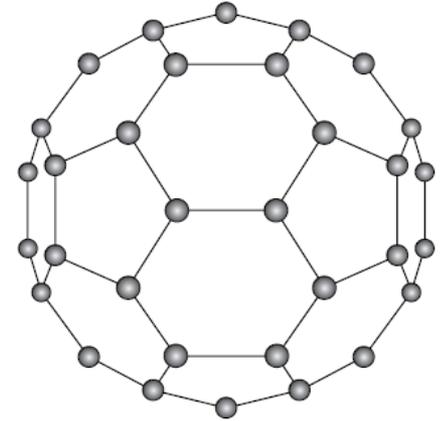


Nota: struttura identica a quella della zincoblenda, dove però la base è carbonio-carbonio invece che Zn-S)

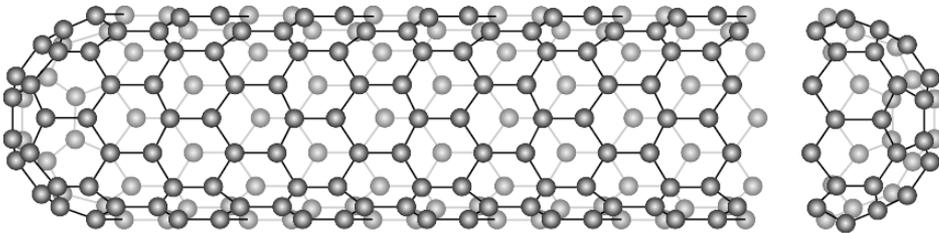
Grafite



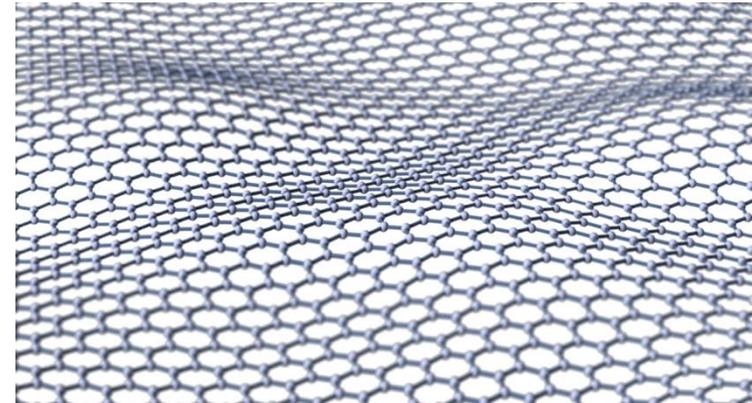
Fullereni



Nanotubi di carbonio

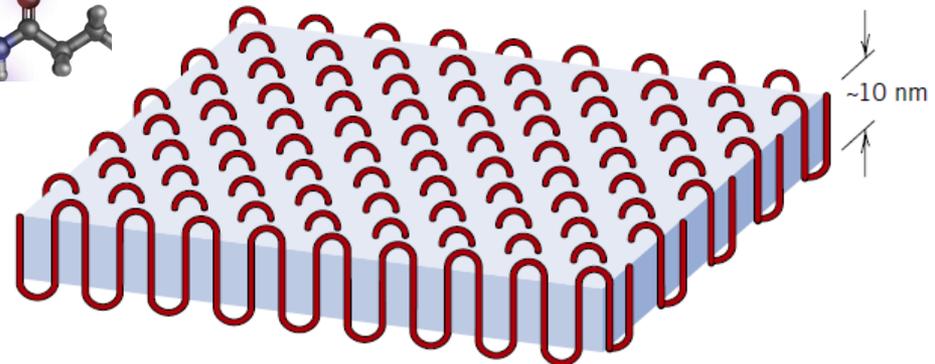
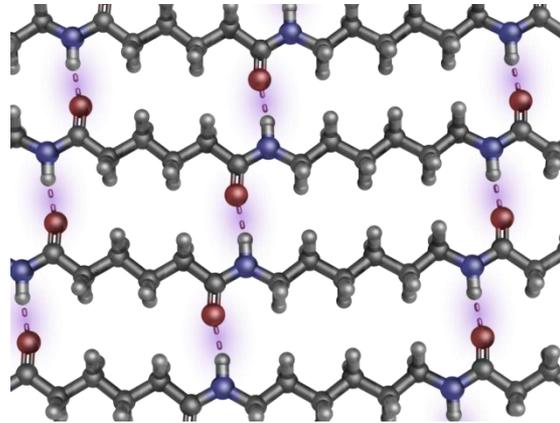
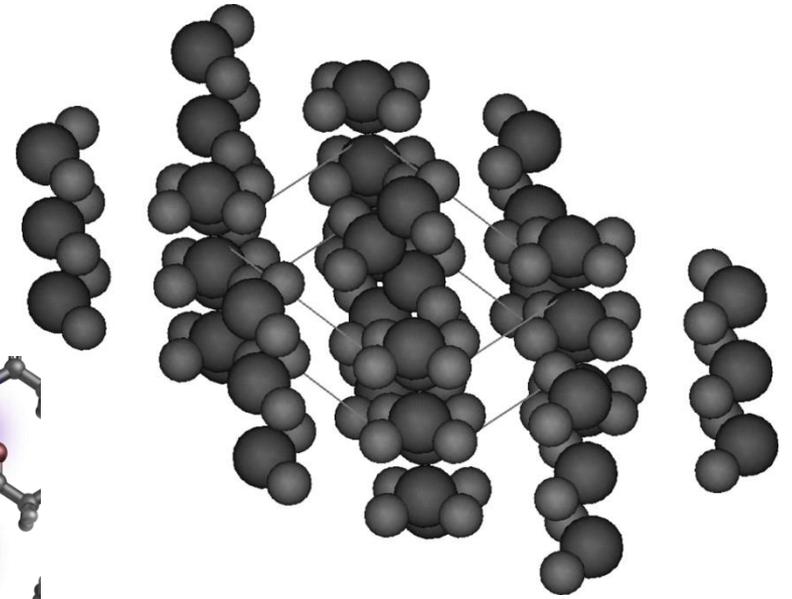
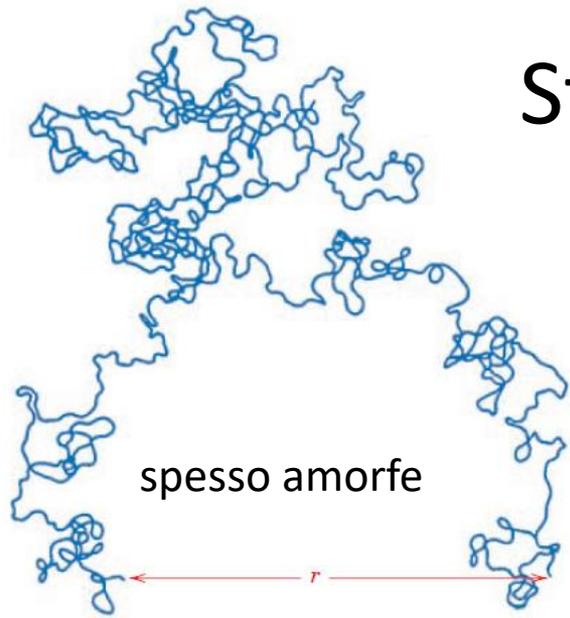


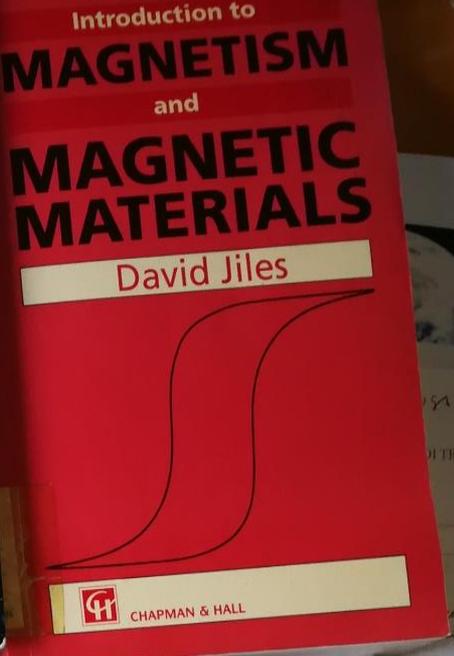
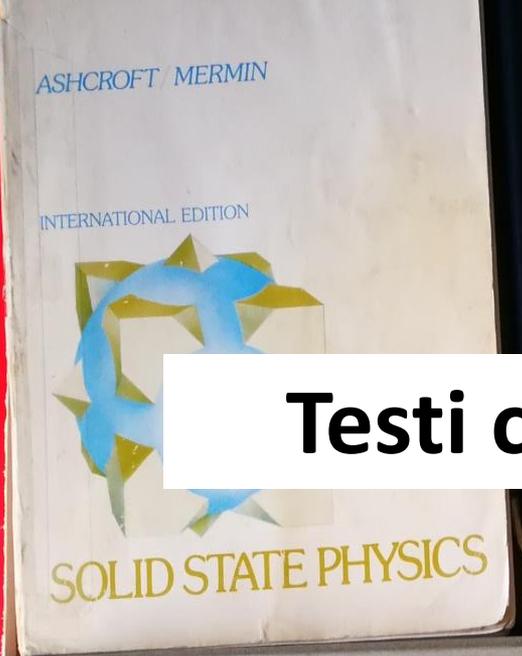
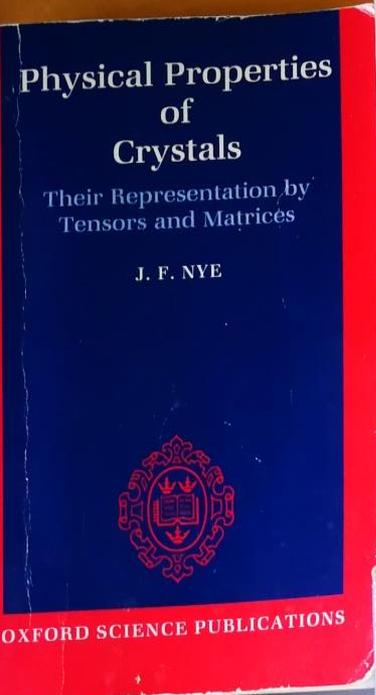
Grafene



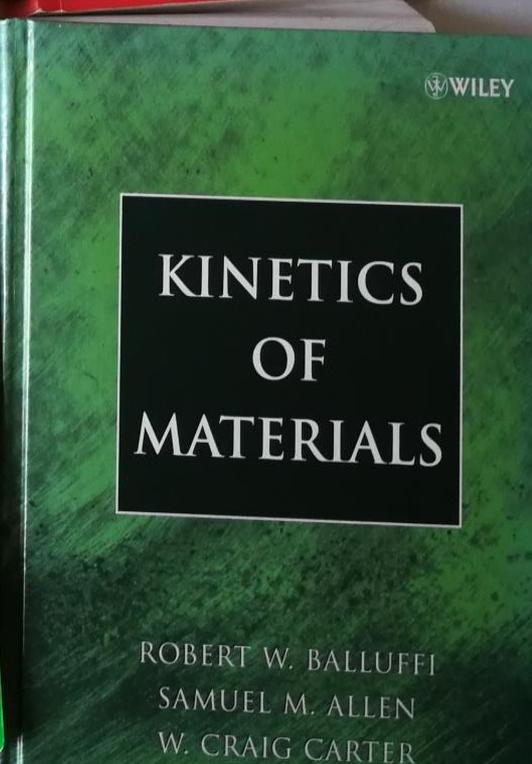
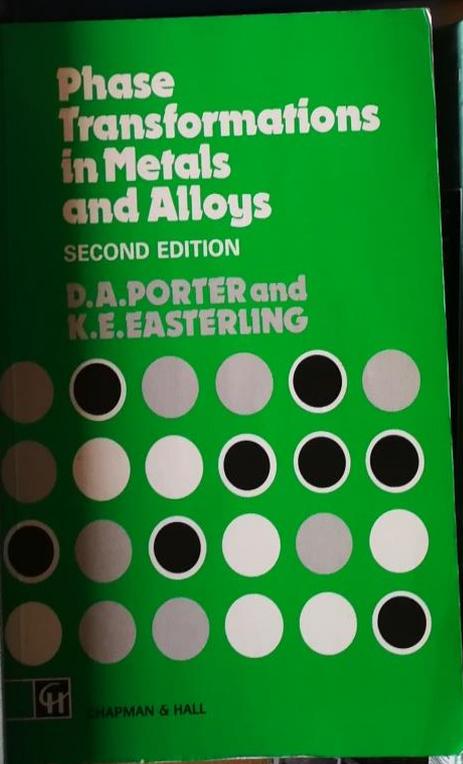
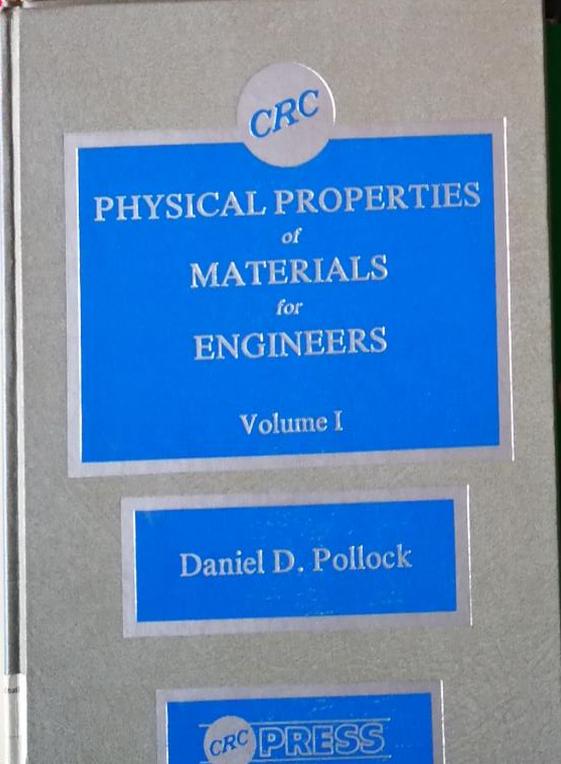
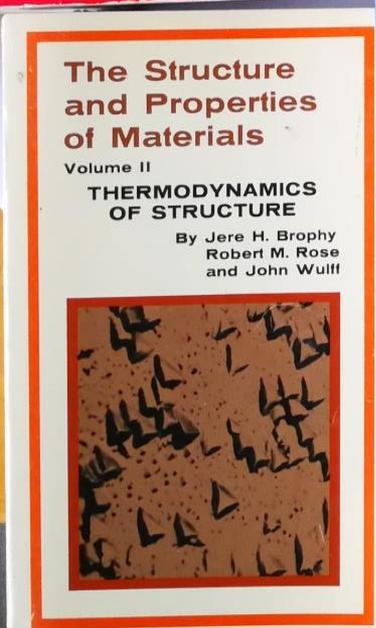
Strutture polimeriche

Possono assumere strutture cristalline
(importanza dei legami intermolecolari)





Testi consigliati



Modalità d'esame

- **Esame orale**
 - Tre domande ampie a discrezione del docente
 - Domande di «teoria», viene richiesto di applicare i concetti, potenzialmente anche con esercizi
- **Appelli**
 - Ufficiali
 - Possibile richiedere appelli straordinari in gruppo durante le sessioni d'esame
 - Appelli fuori sessione solo per studenti fuori corso