UNIVERSITY OF CAMBRIDGE

Electric polarisation in materials

Lecture 2

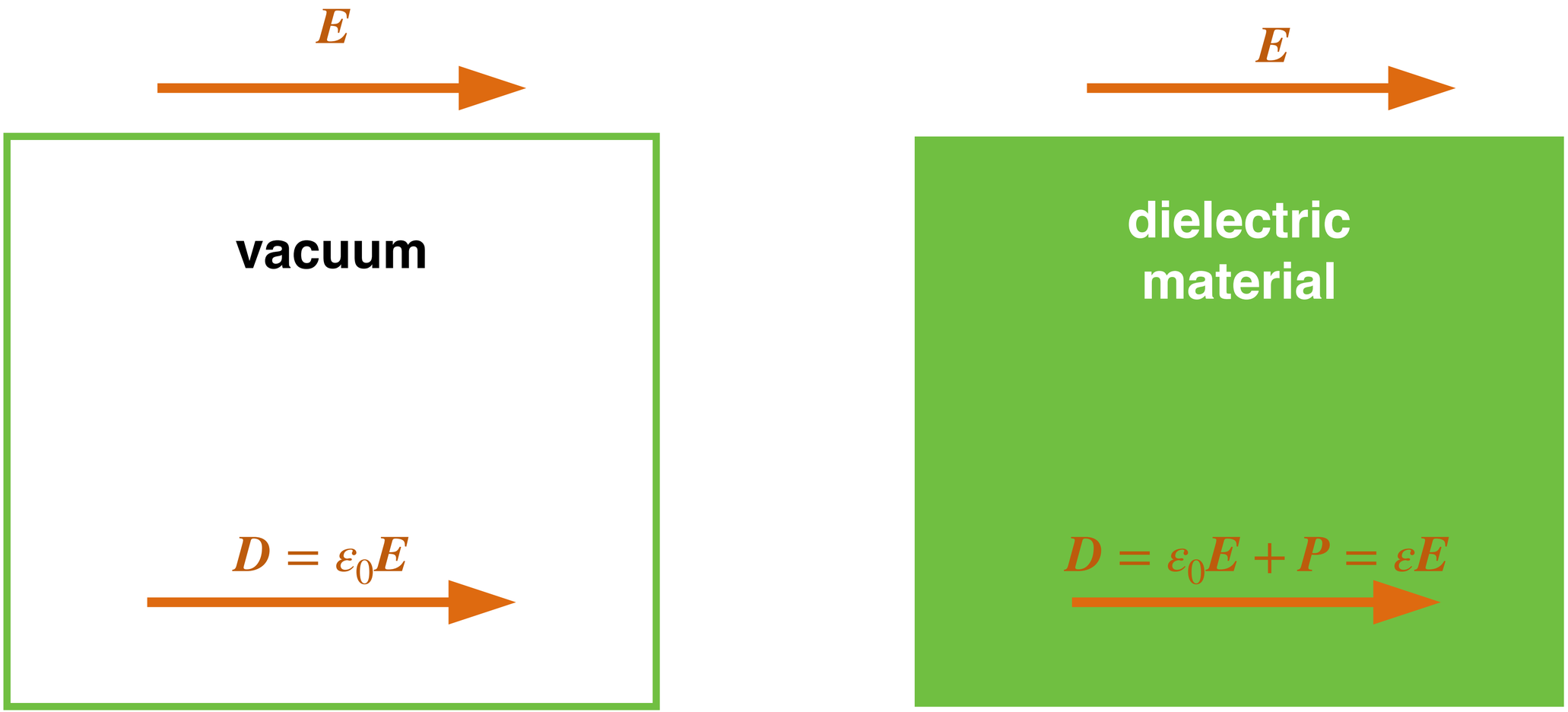
Bartomeu Monserrat
Course B: Materials for Devices

Professor M does Science

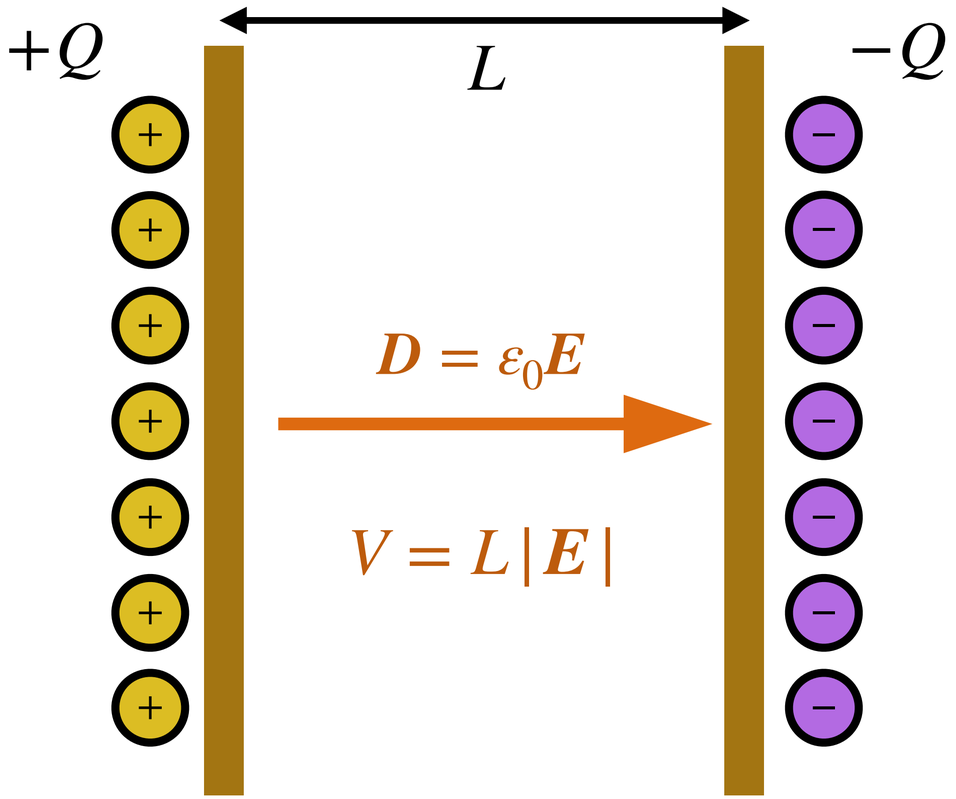
http://www.tcm.phy.cam.ac.uk/~bm418/

Dielectric materials

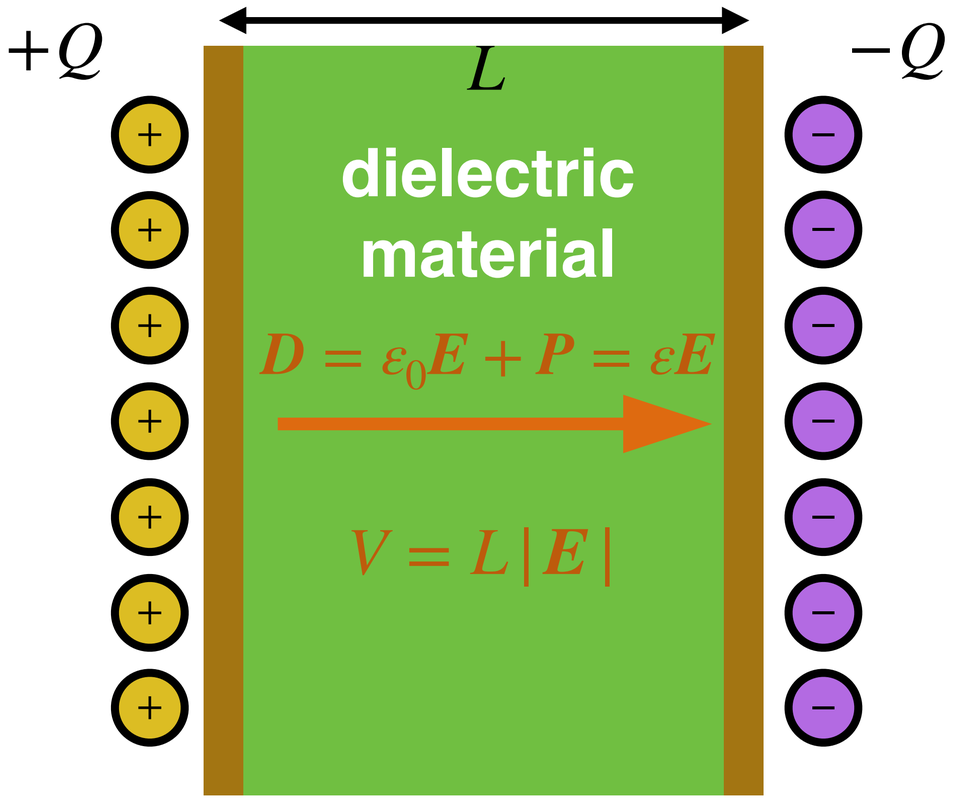
- Dielectric material: electrical insulator that can be polarised by applied electric field



Parallel plate capacitor



$$C = \frac{Q}{V} = \varepsilon_0 \frac{A}{L}$$

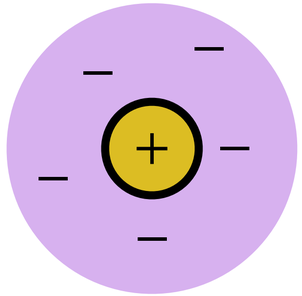


$$C = \frac{Q}{V} = \varepsilon \frac{A}{L}$$

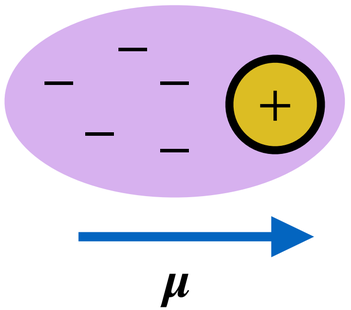
Polarisation mechanisms

electronic polarisation

$\mathbf{E} = 0$

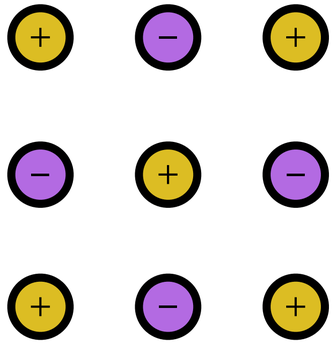


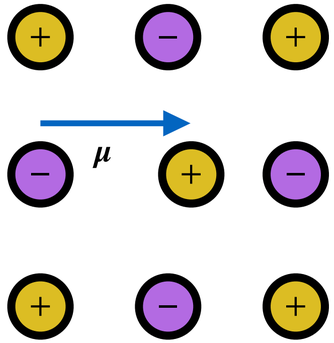
$\mathbf{E}$



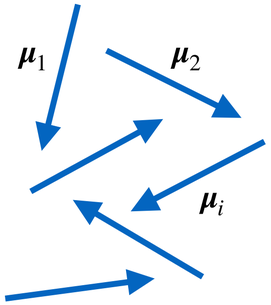
ionic polarisation

$\boldsymbol{\mu} = \mathbf{0}$

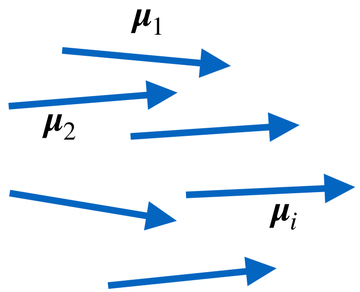




orientation polarisation



$$\boldsymbol{\mu} = \sum_{i=1}^{N} \boldsymbol{\mu}_i \simeq 0$$



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Polarisation mechanisms

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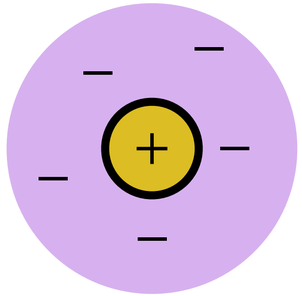
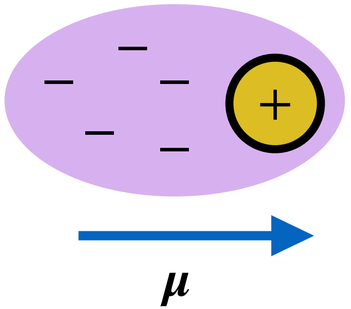


$\mathbf{E}$



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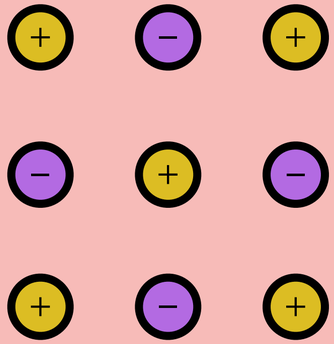

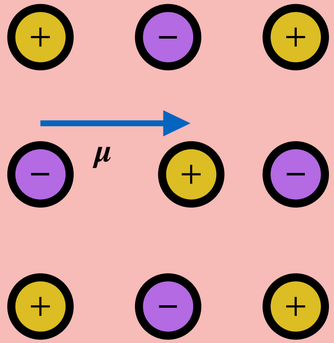

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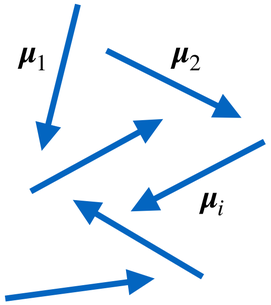

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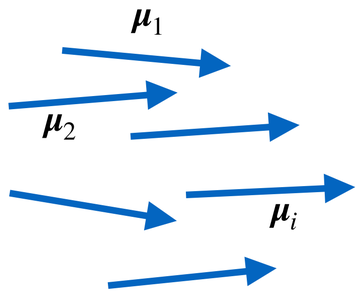

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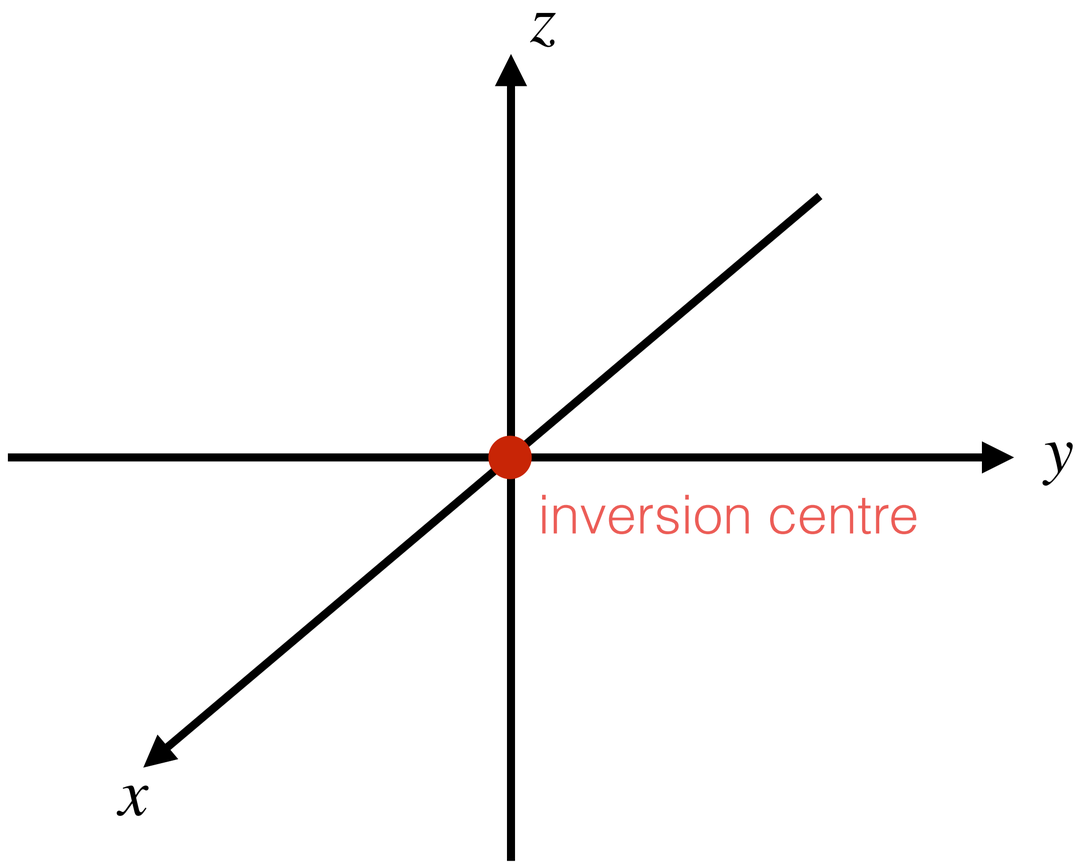
Centrosymmetric crystals

- A centrosymmetric crystals has an **inversion centre**



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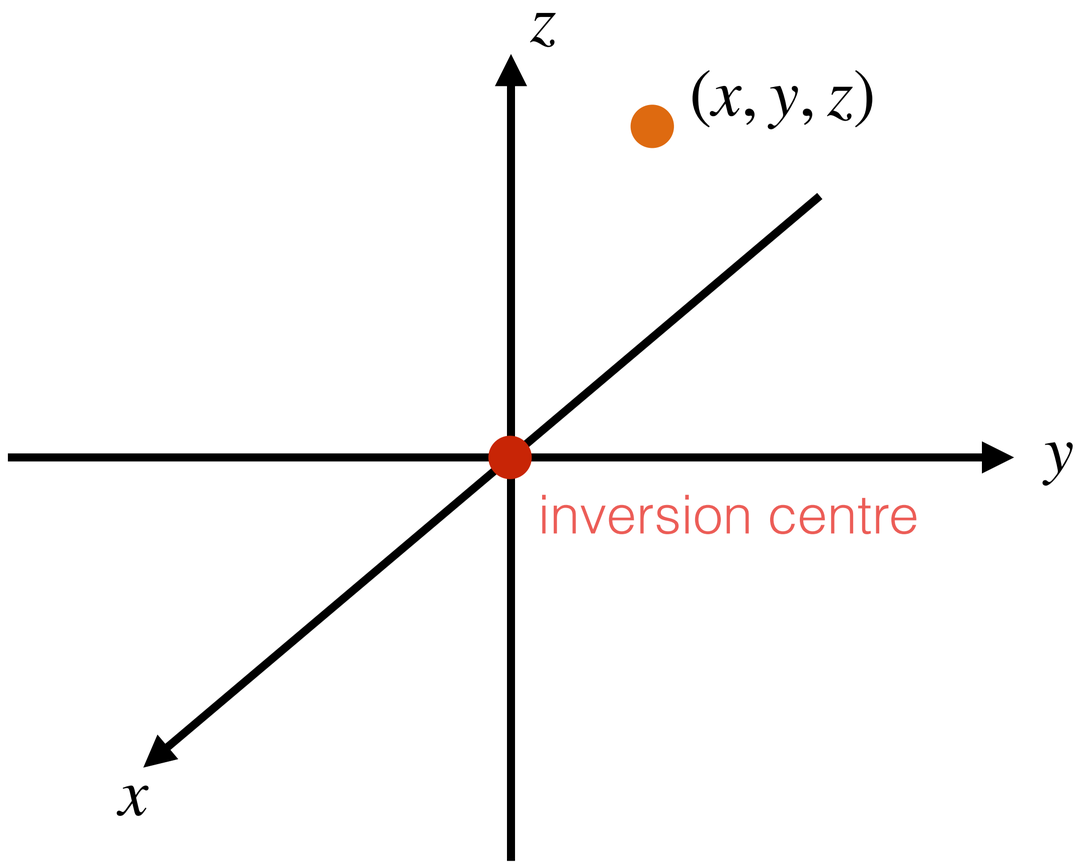

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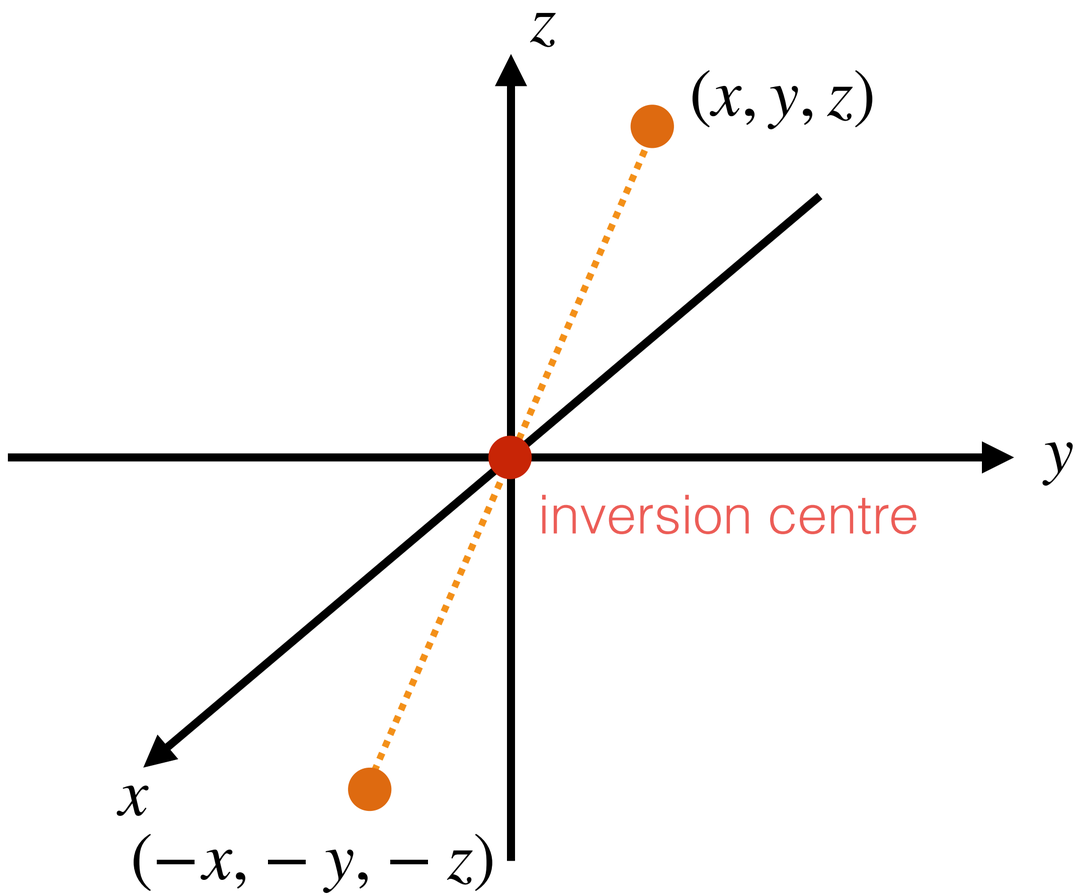

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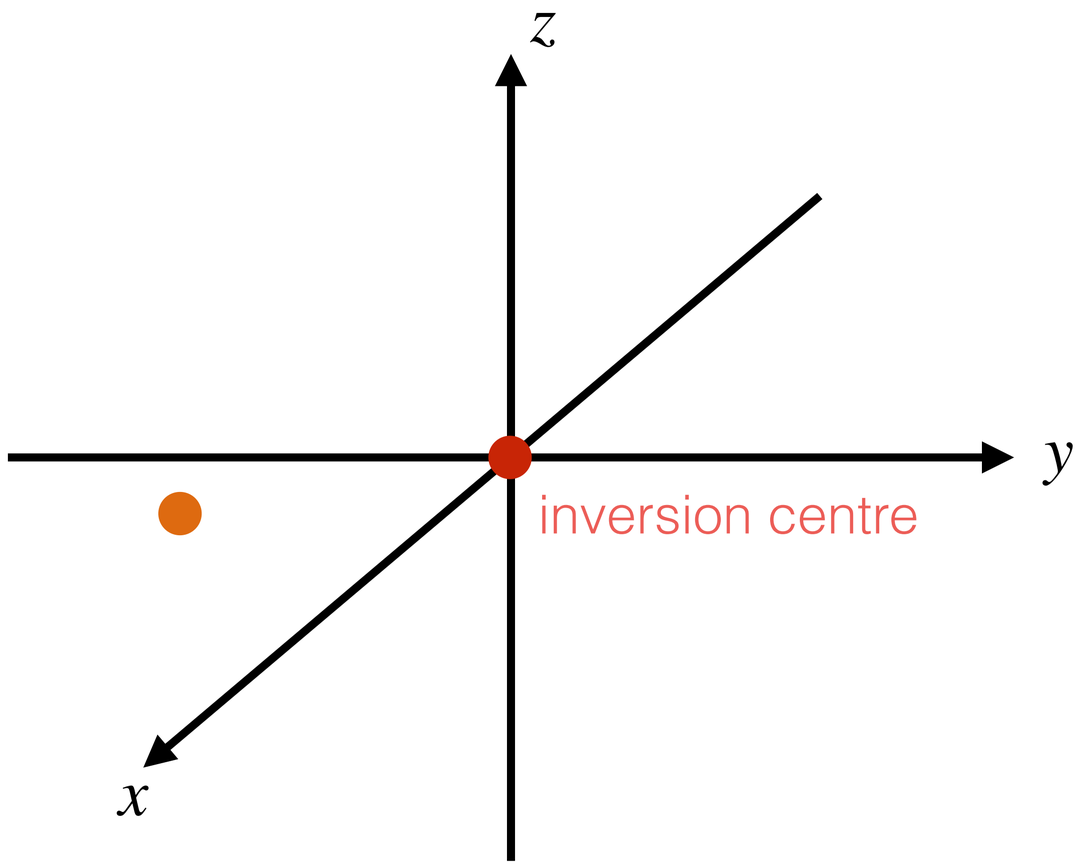

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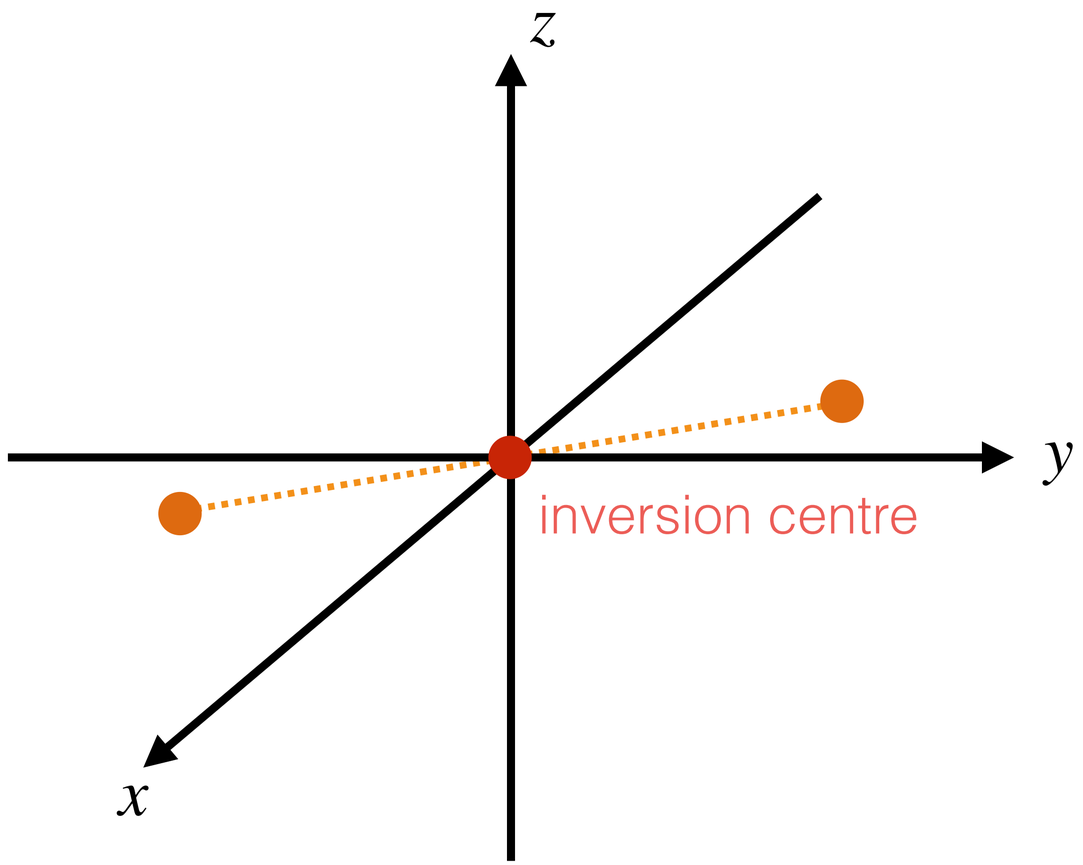

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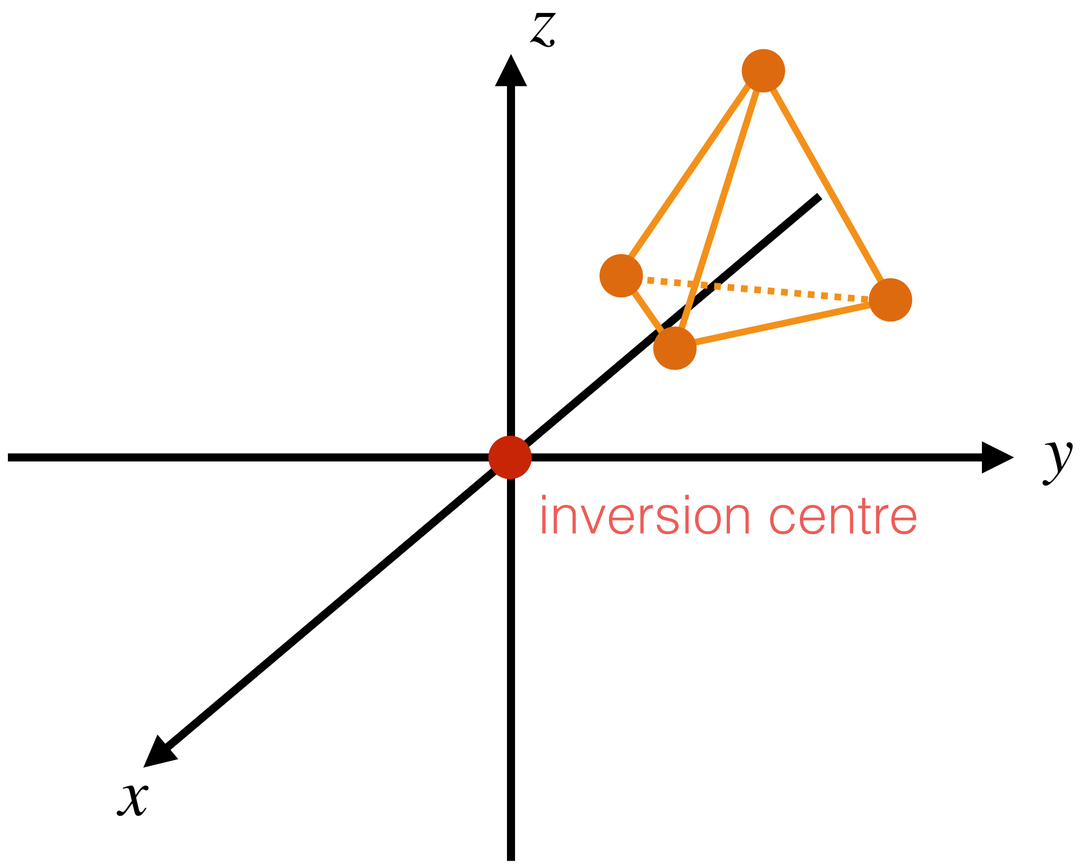

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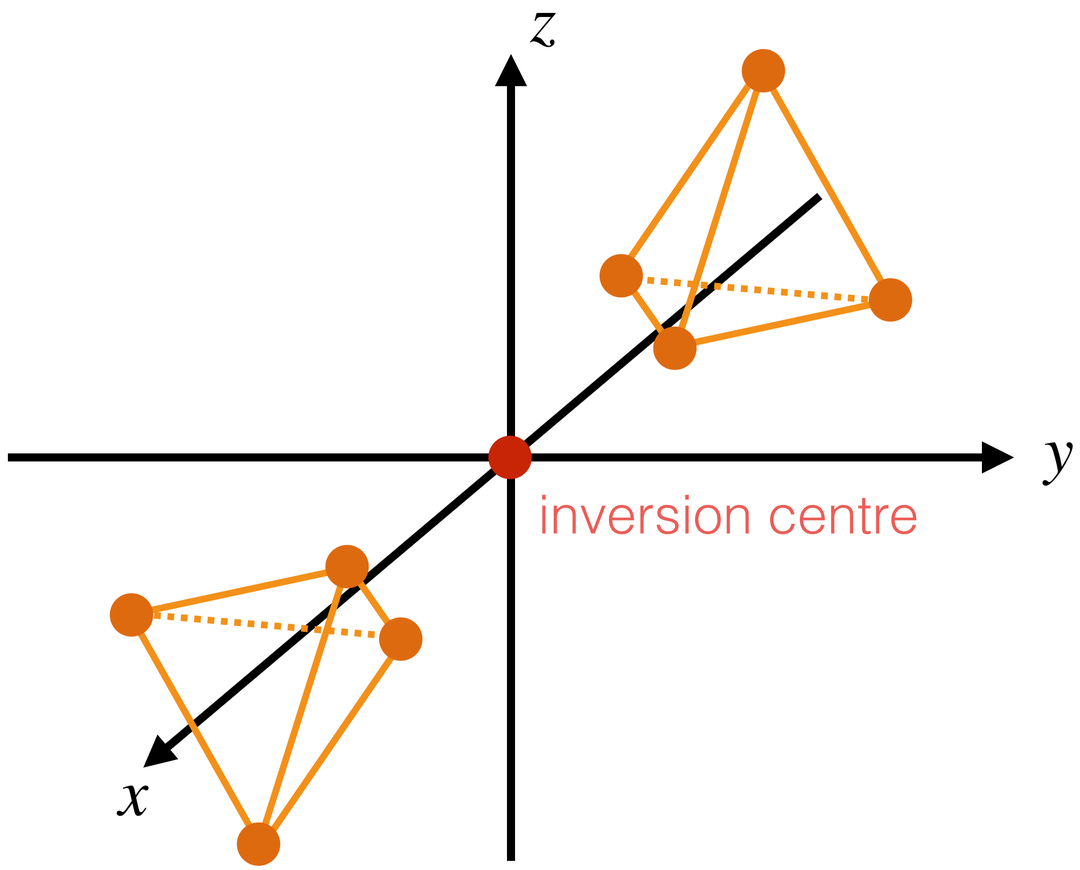

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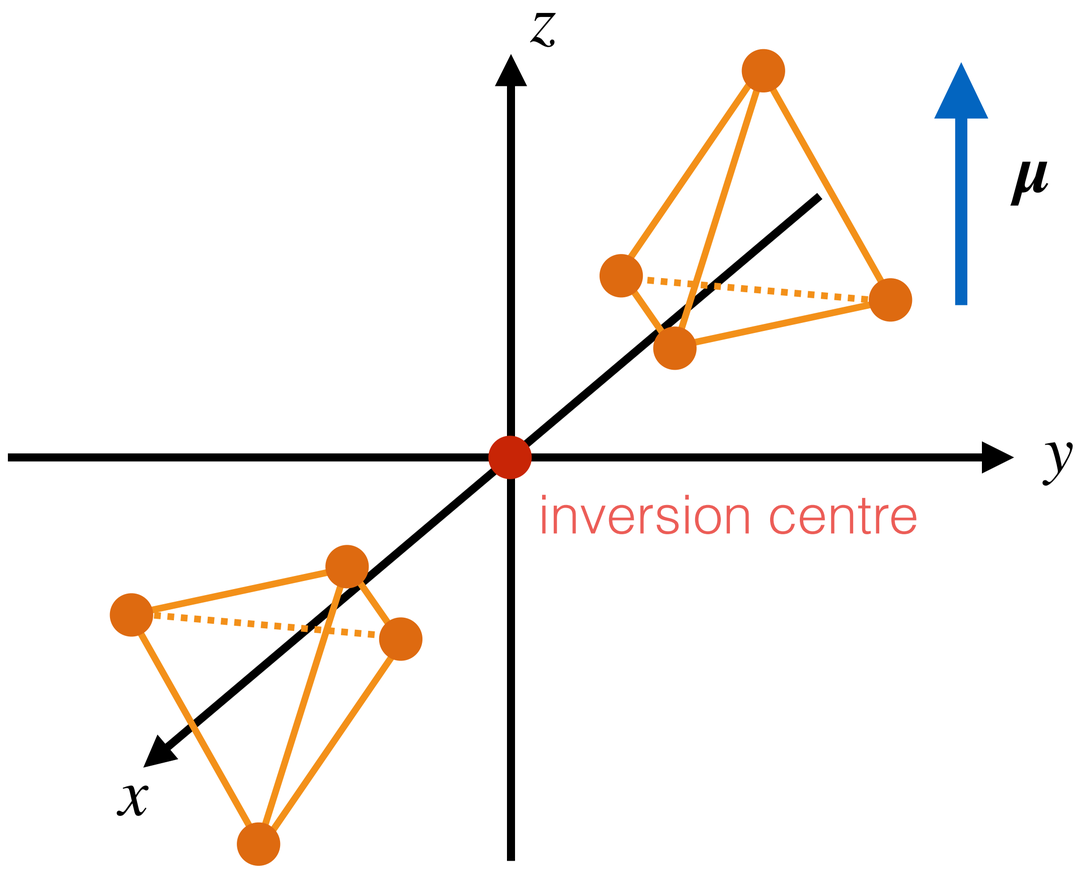

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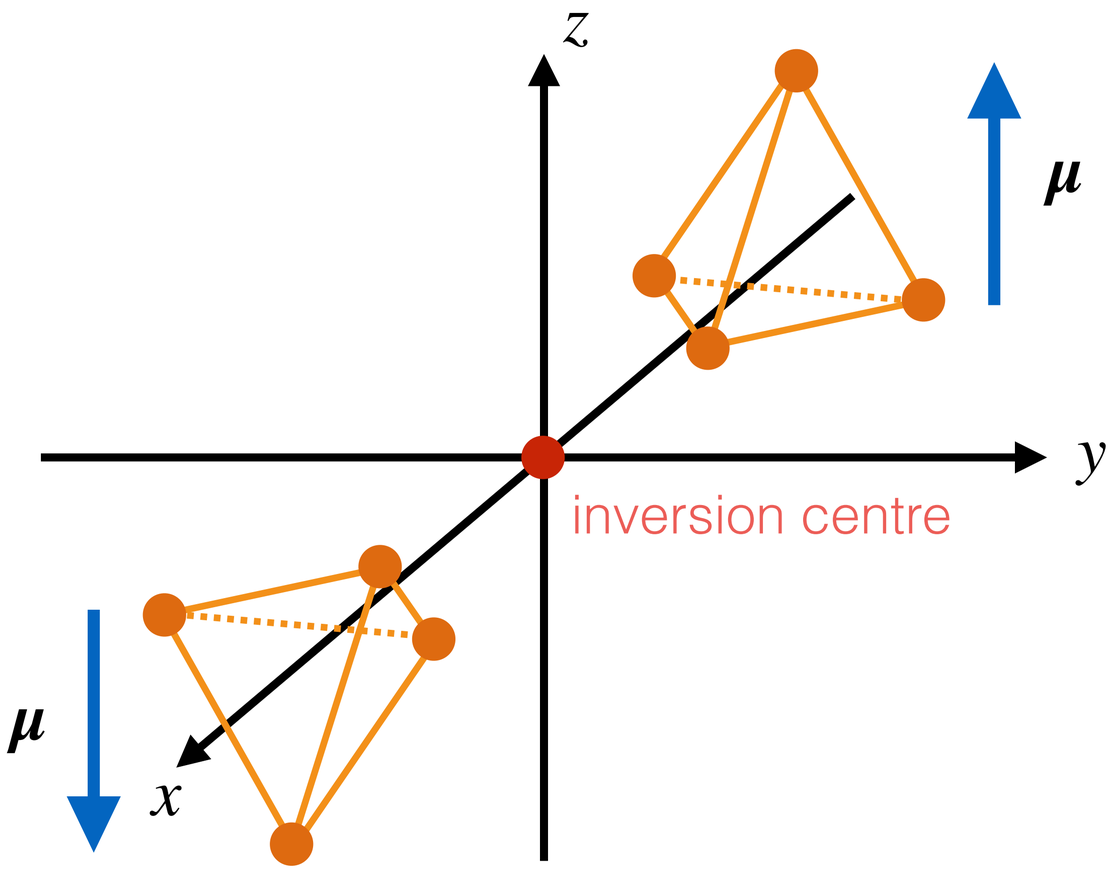

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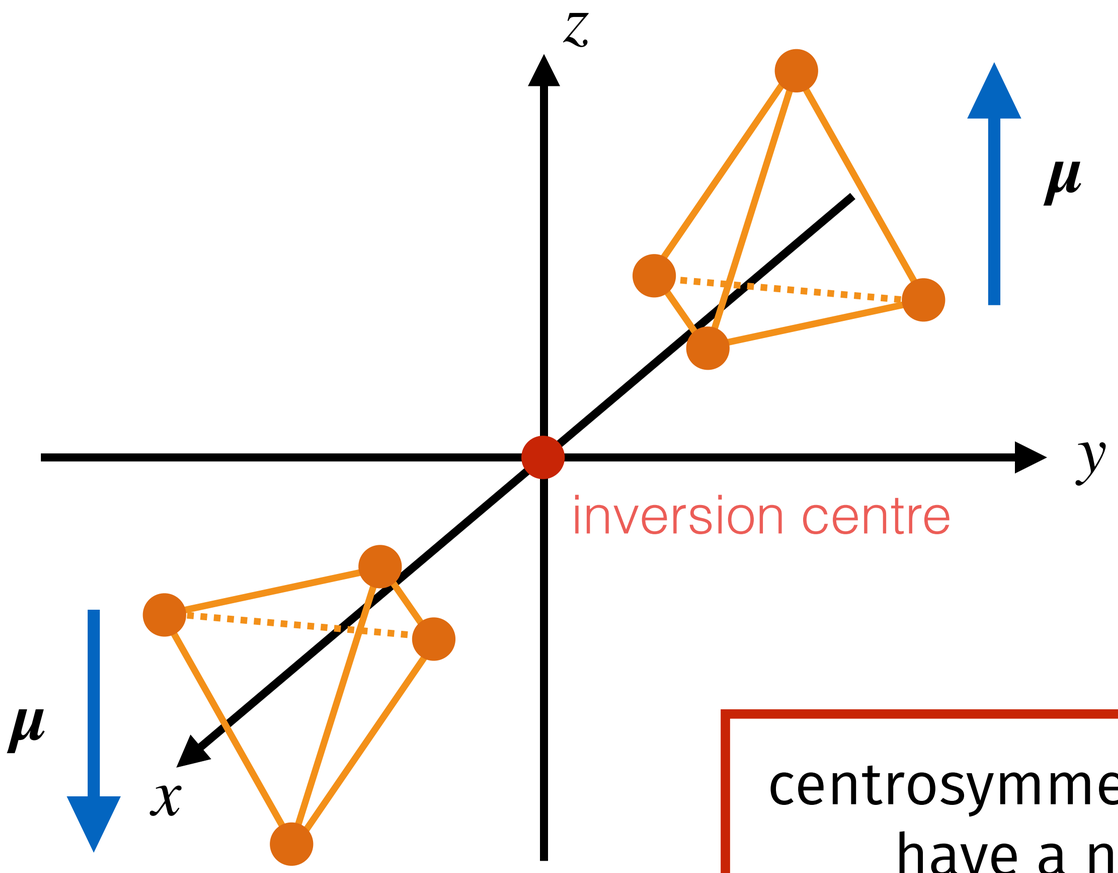
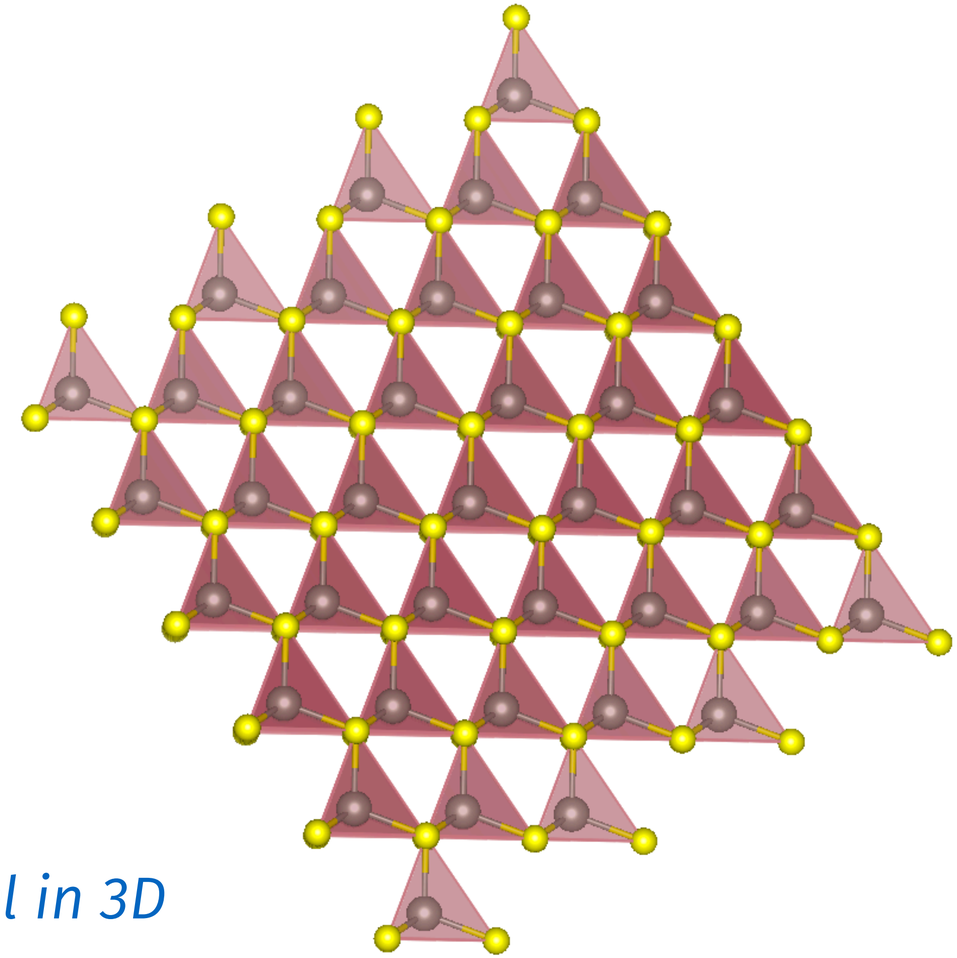


centrosymmetric crystals cannot have a net polarisation

Non-centrosymmetric crystals

- A non-centrosymmetric crystals does not have an **inversion centre**

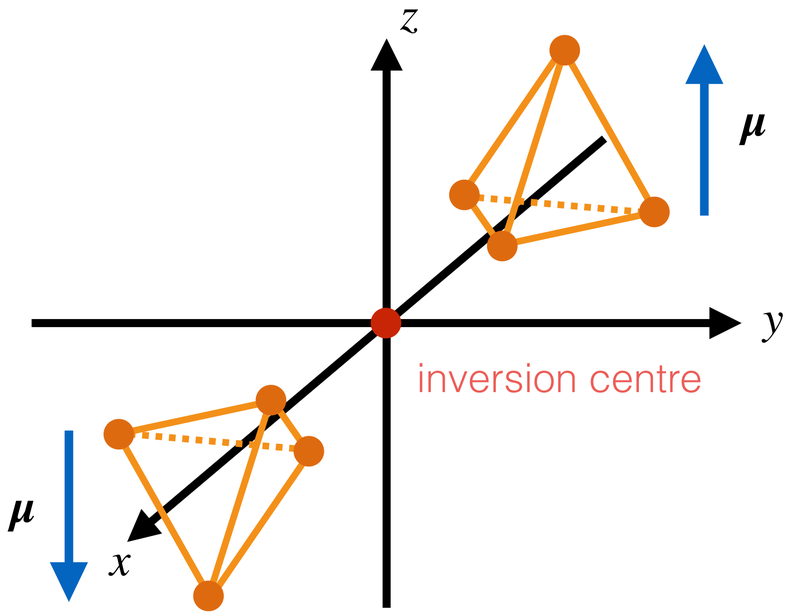


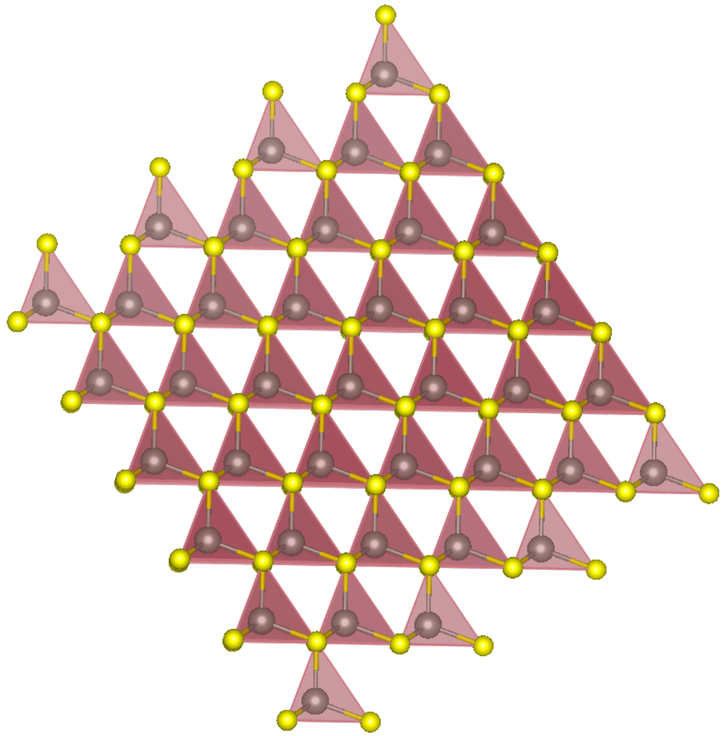
- ZnS (zinc blende)
- Face-centred cubic (fcc)
- Two-atom basis
- Course A: sphalerite

- *See structure model in 3D*

Non-centrosymmetric crystals: non-polar

- A non-centrosymmetric crystals does not have an **inversion centre**
- Are all non-centrosymmetric crystals polar?





Non-centrosymmetric crystals: non-polar

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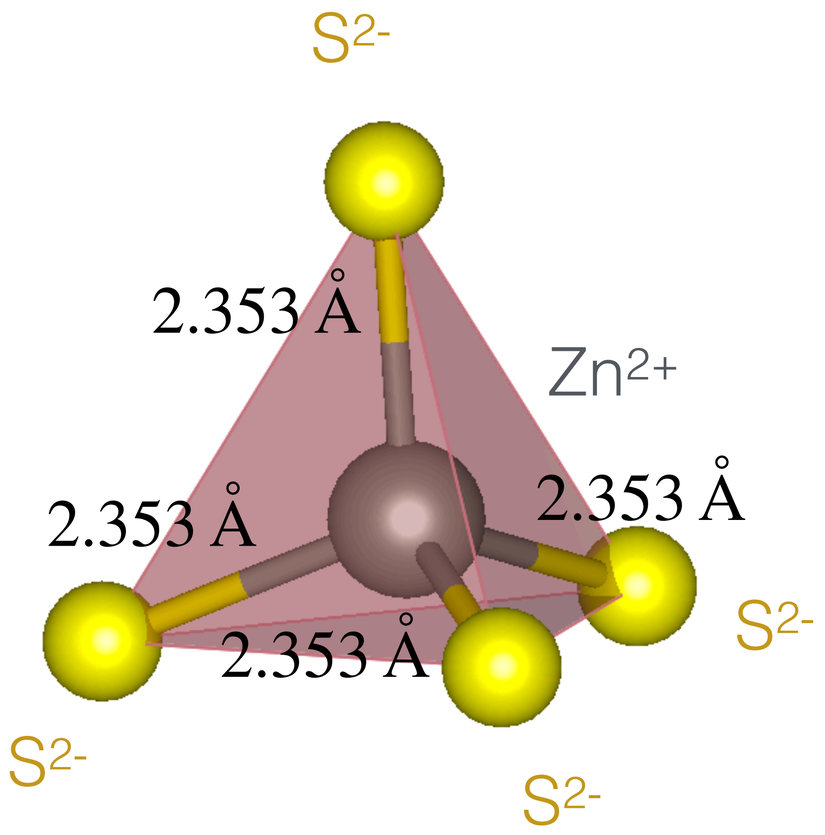
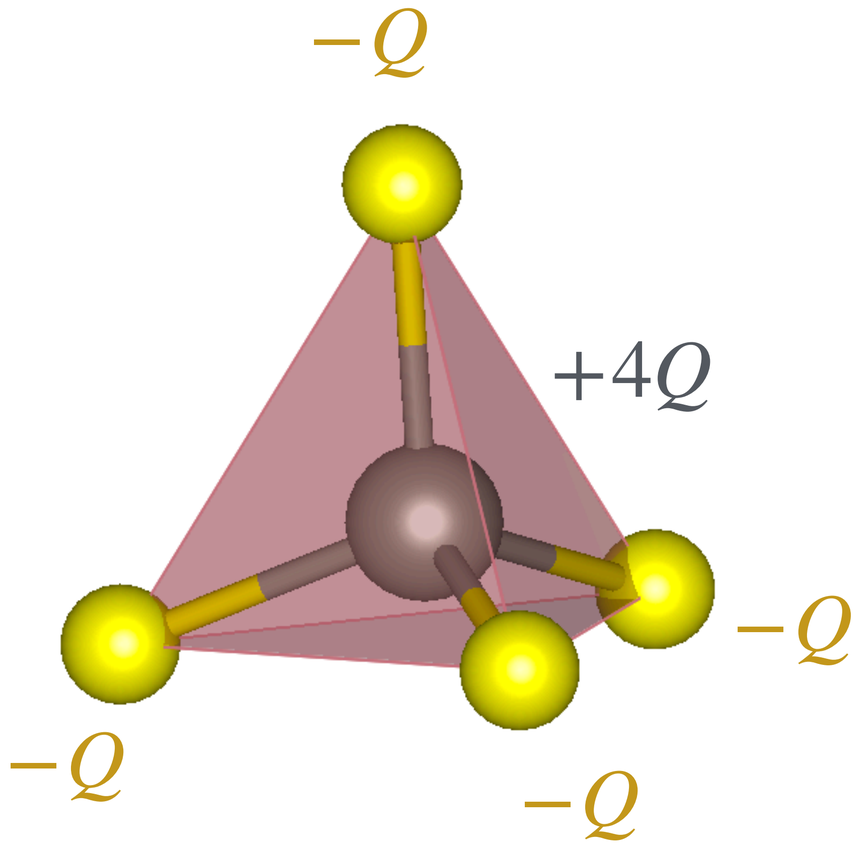


S: [Ne] $3s^2$ $3p^4$

Zn: [Ar] $3d^{10}$ $4s^2$

Non-centrosymmetric crystals: non-polar

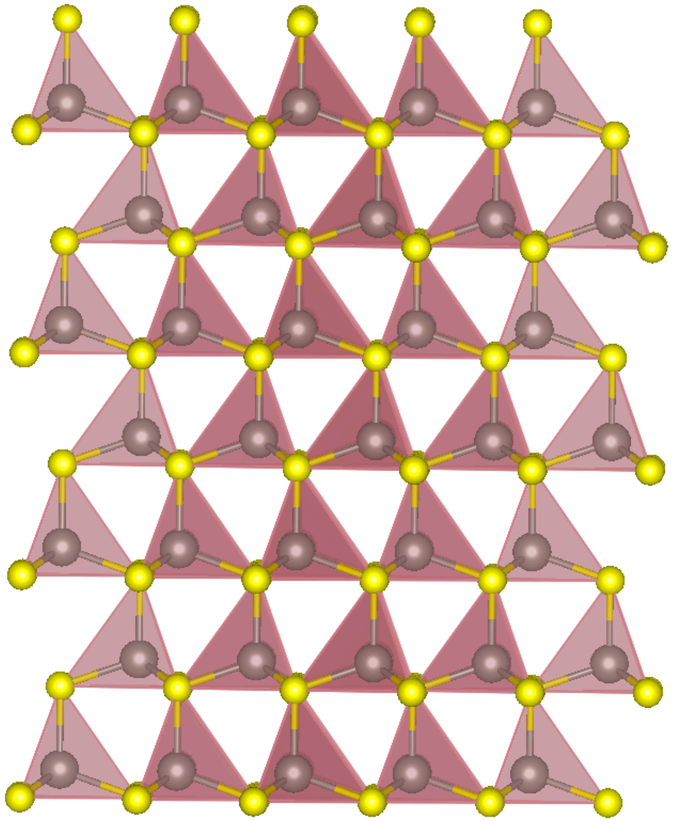
- A non-centrosymmetric crystals does not have an **inversion centre**
- Are all non-centrosymmetric crystals polar?



no net dipole

Non-centrosymmetric crystals: polar

- A non-centrosymmetric crystals does not have an **inversion centre**
- A non-centrosymmetric crystals can be **polar**



- ZnS (wurtzite)
- Hexagonal
- Four-atom basis
- Course A

- *See structure model in 3D*

Non-centrosymmetric crystals: non-polar

- A non-centrosymmetric crystals does not have an **inversion centre**
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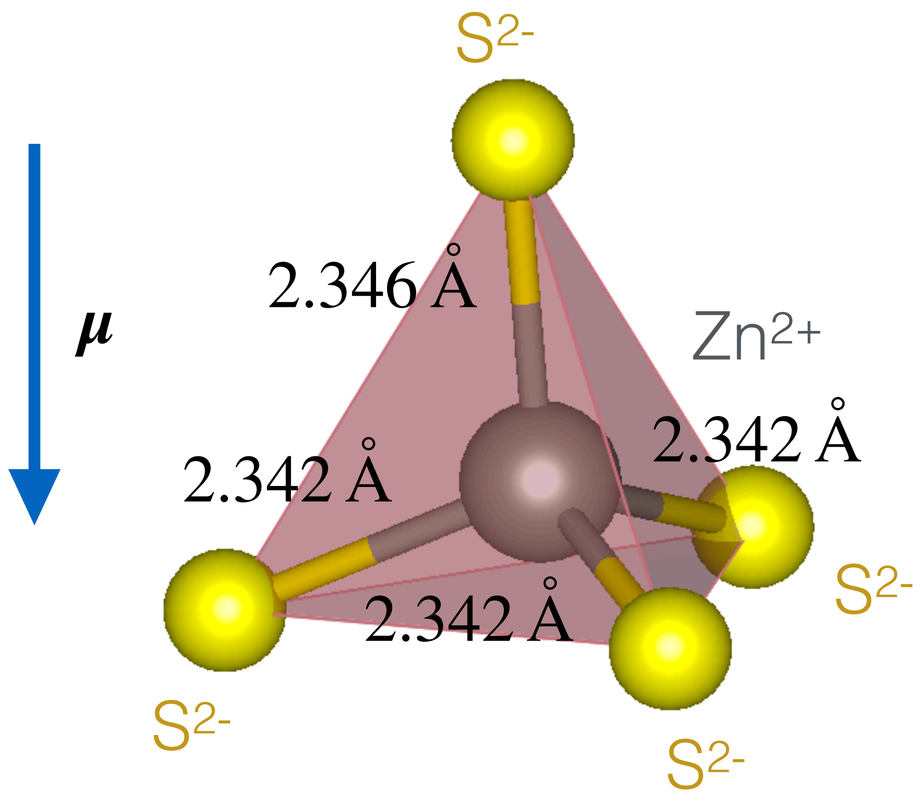


S: [Ne] $3s^2$ $3p^4$

Zn: [Ar] $3d^{10}$ $4s^2$

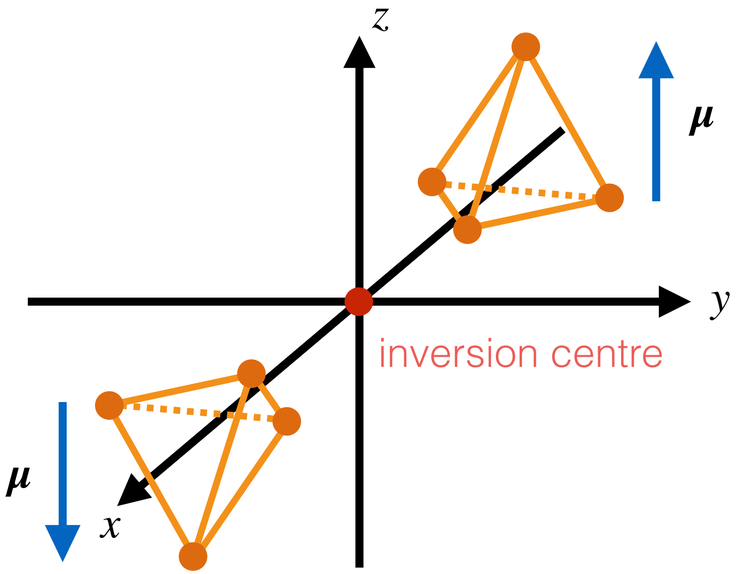
centrosymmetric crystal

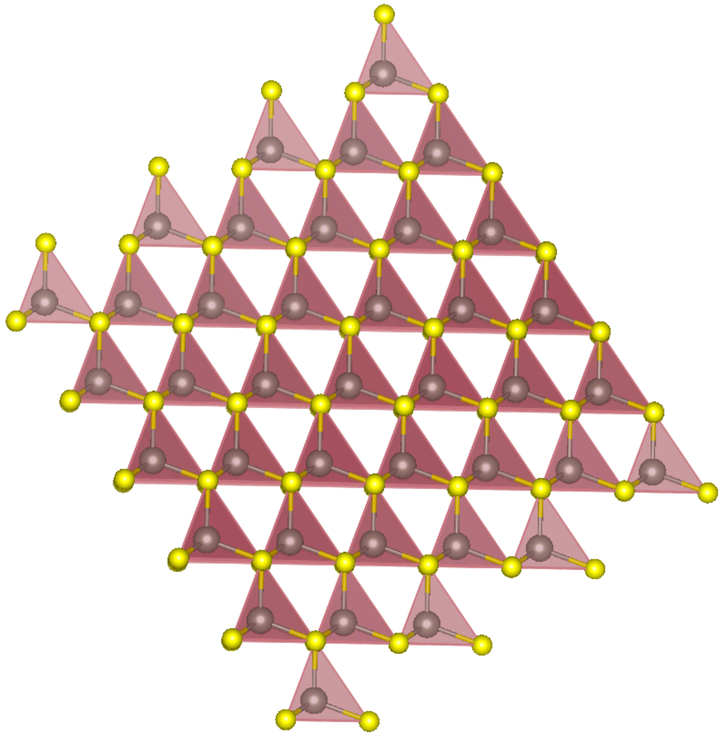
noncentrosymmetric crystal

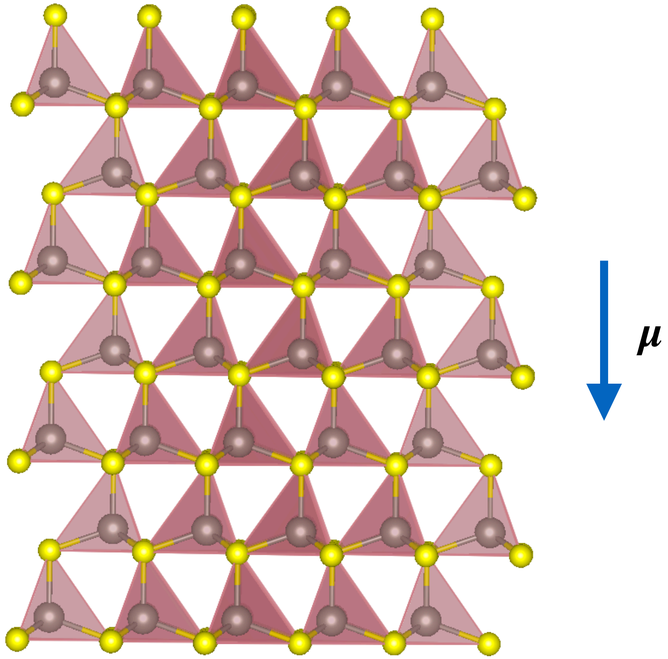
non-polar

non-polar

polar

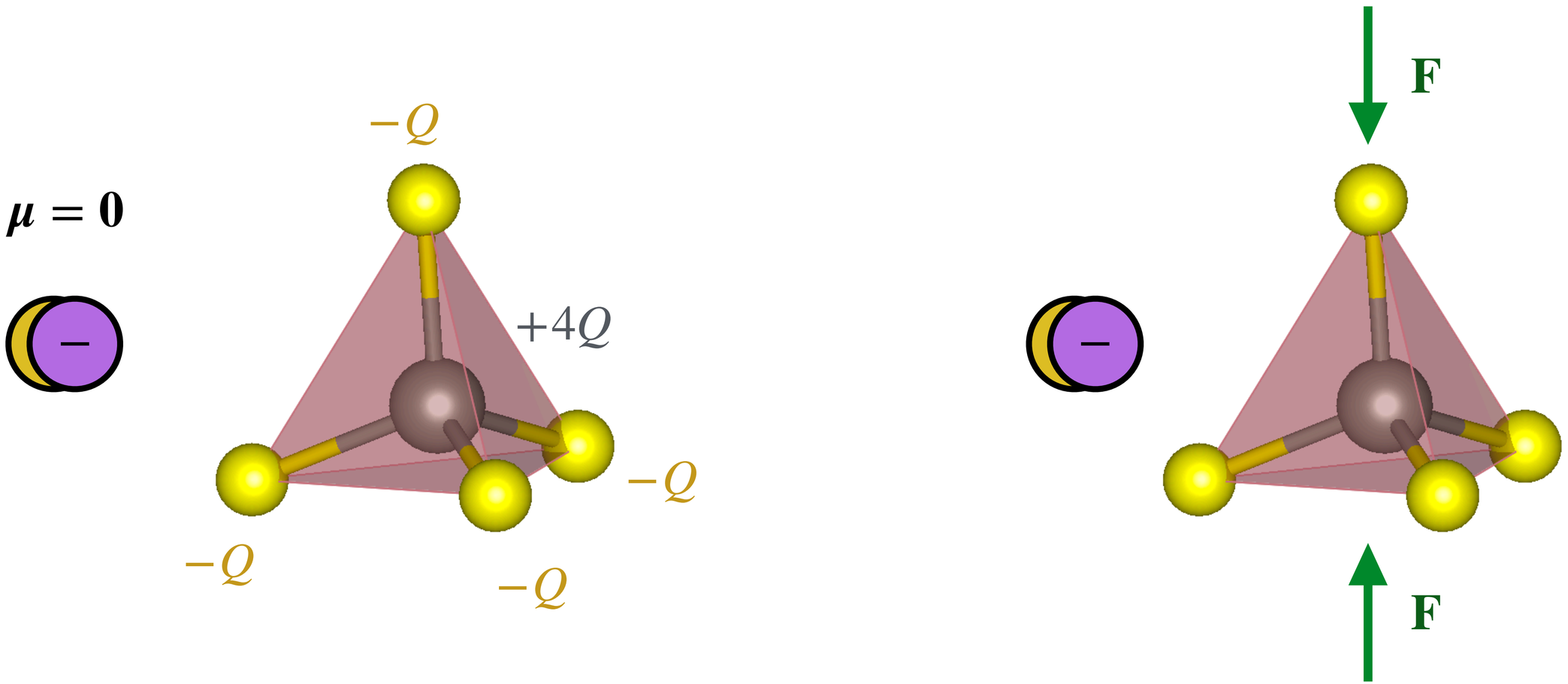






Piezoelectricity

- Piezoelectricity: dipole moment change due to the application of stress



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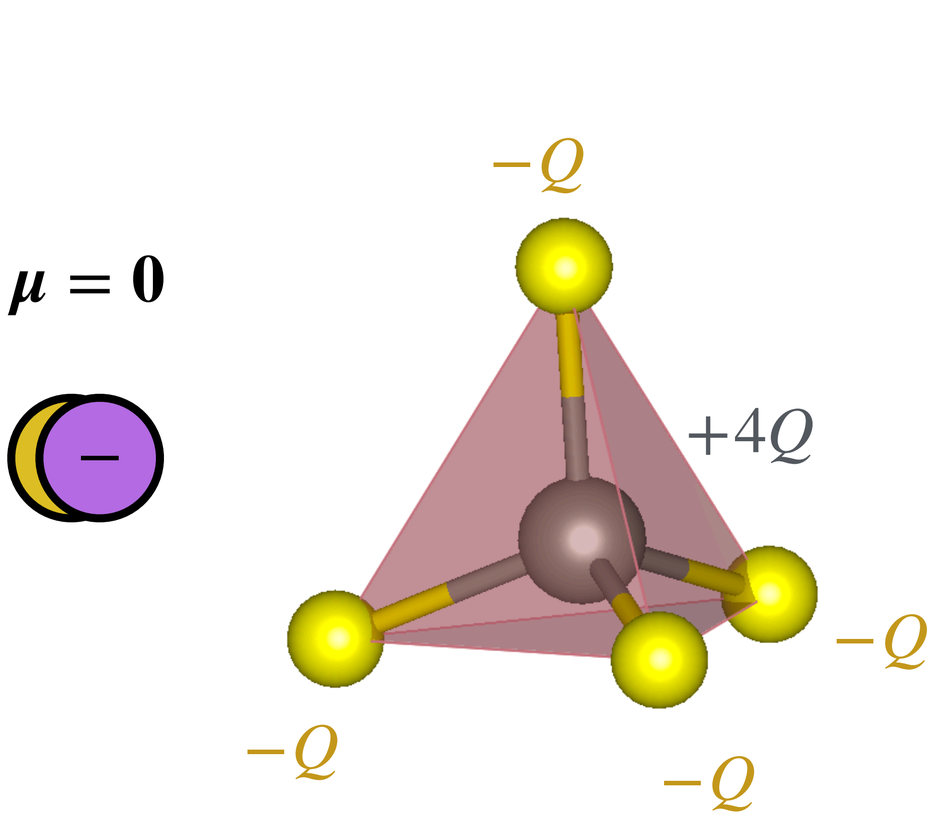
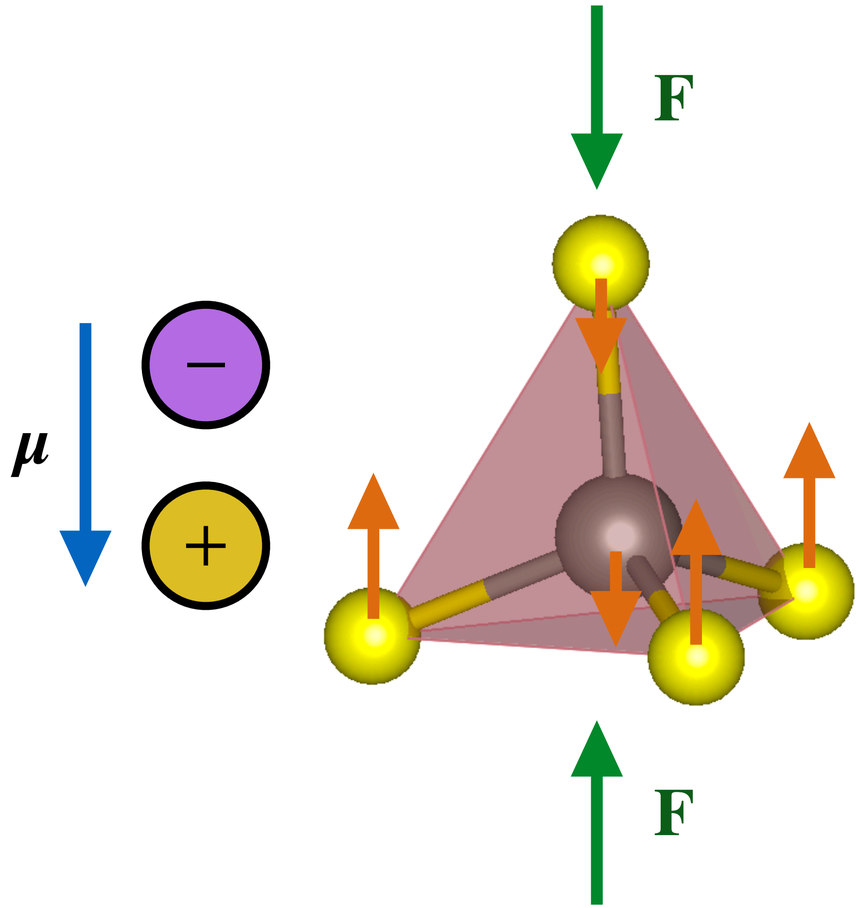




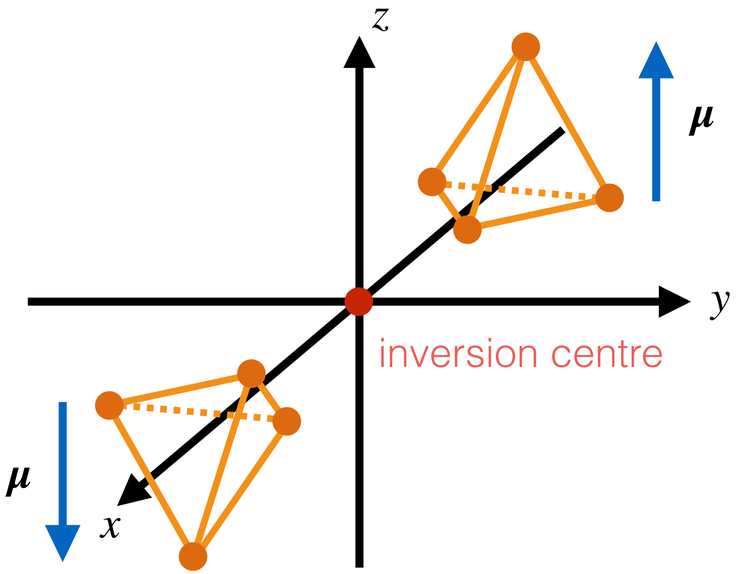
centrosymmetric crystal

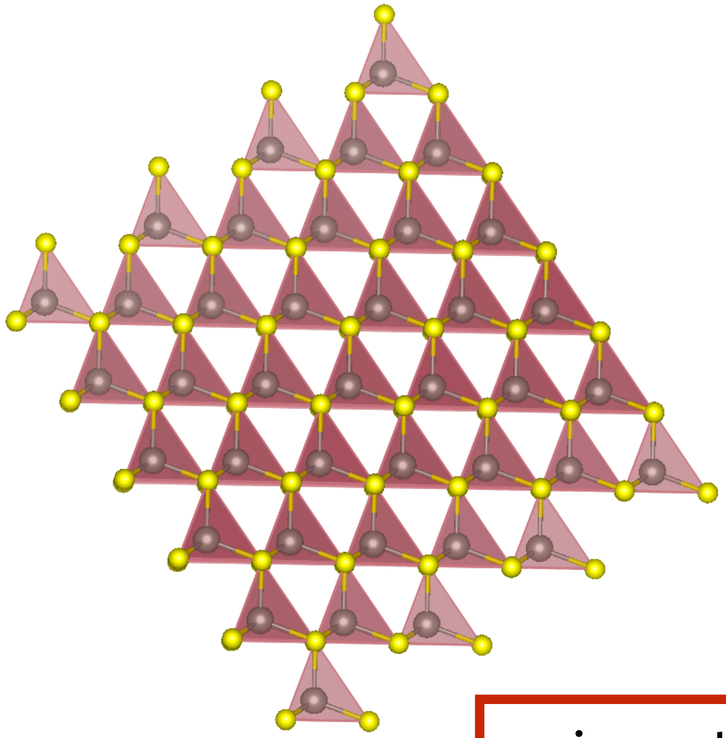
noncentrosymmetric crystal

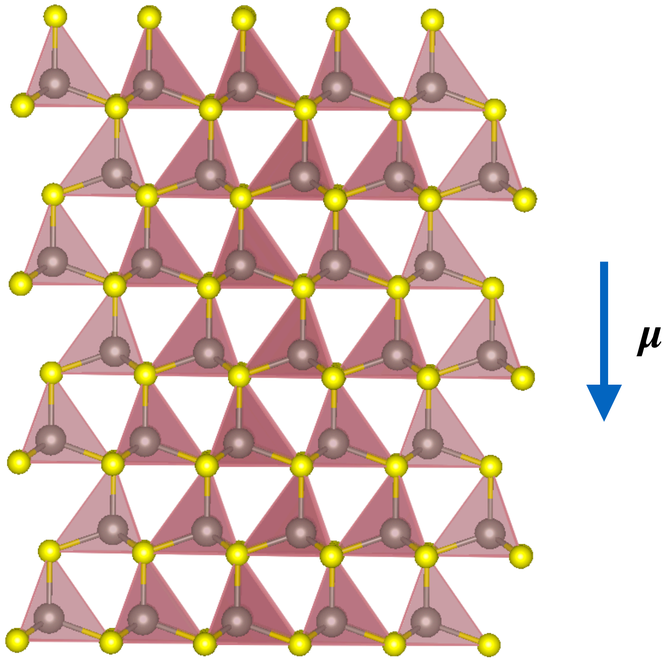
non-polar

non-polar

polar







no piezoelectricity

piezoelectricity*

* Cubic crystal class 432 exception

Piezoelectricity

- *See discussion of piezoelectricity in rectangular prism*

$$\Delta V = \frac{dTL}{\varepsilon}$$

ΔV : change in potential $[\mathrm{V}]$

d : piezoelectric coefficient $[\mathrm{C\,N^{-1}}]$

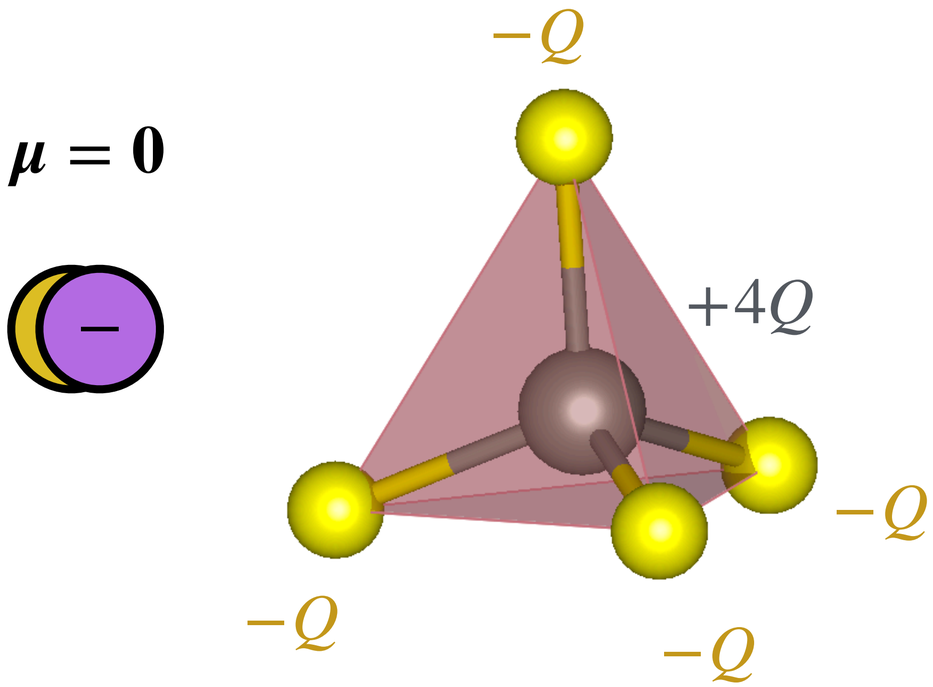
T : stress $[\mathrm{Nm^{-2}}]$

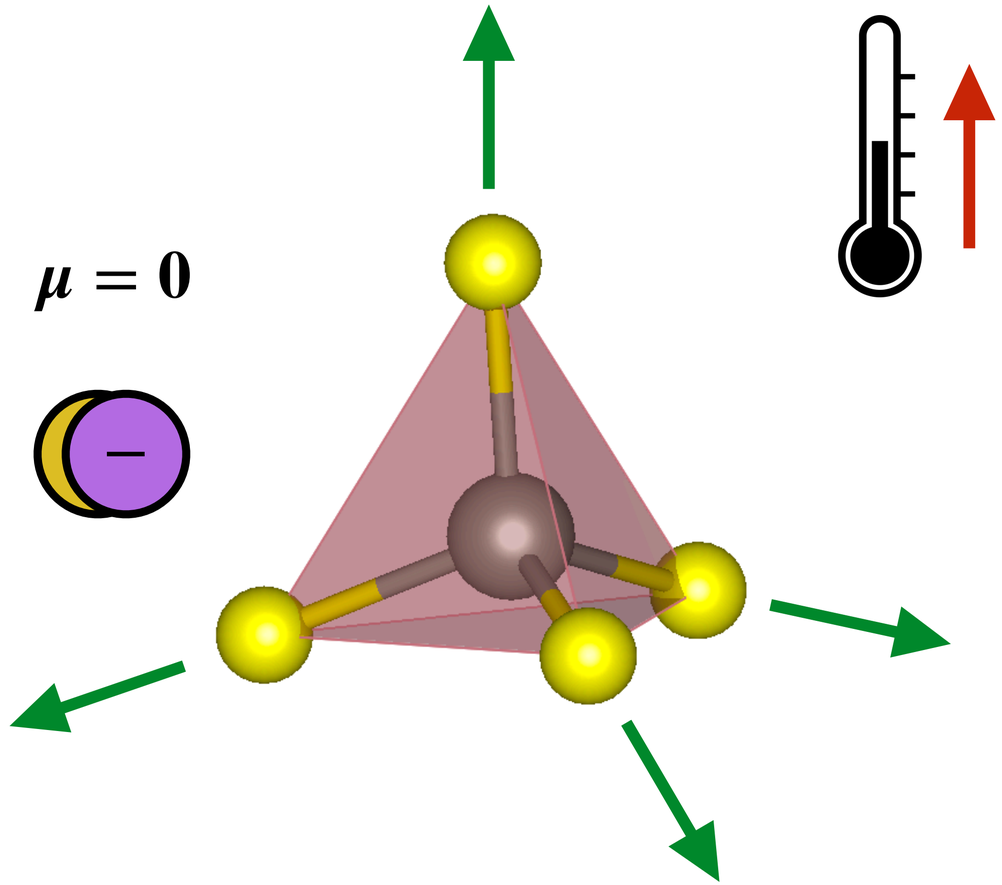
L : length of prism $[\mathrm{m}]$

ε : permittivity $[\mathrm{Fm^{-1}} = \mathrm{CV^{-1}m^{-1}}]$

Pyroelectricity

- Pyroelectricity: dipole moment change due to temperature change





Pyroelectricity

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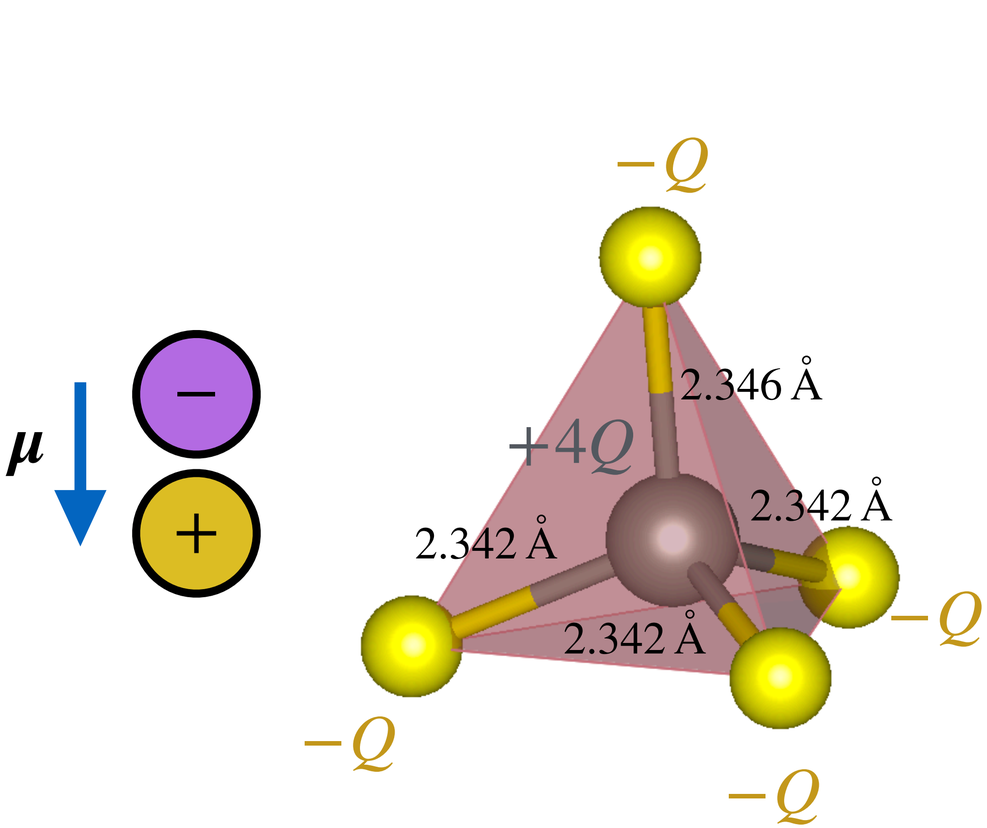
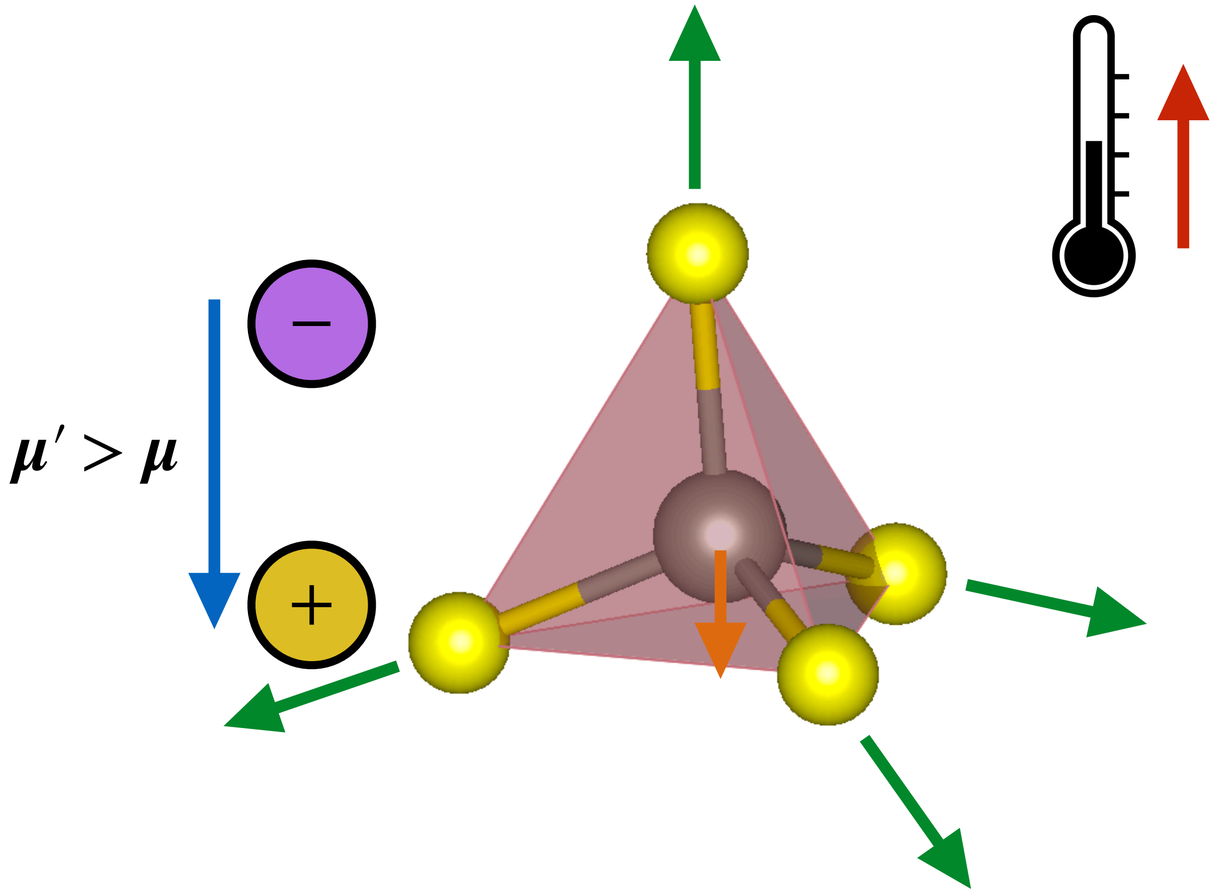




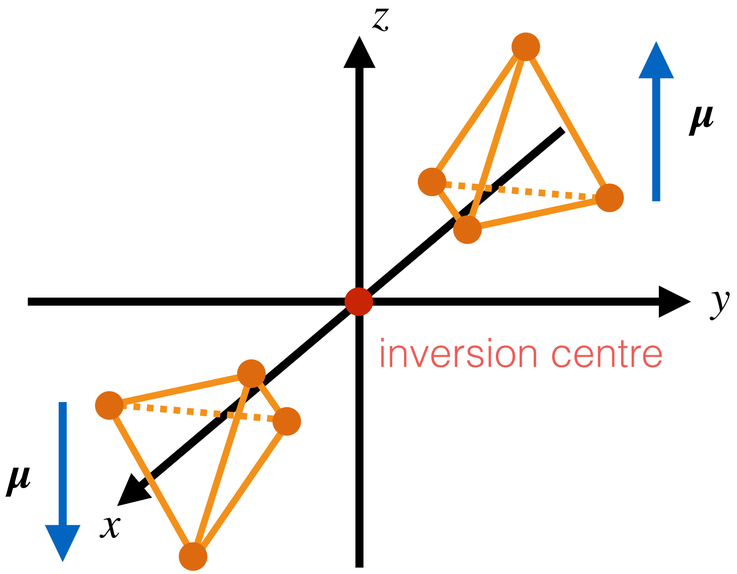
centrosymmetric crystal

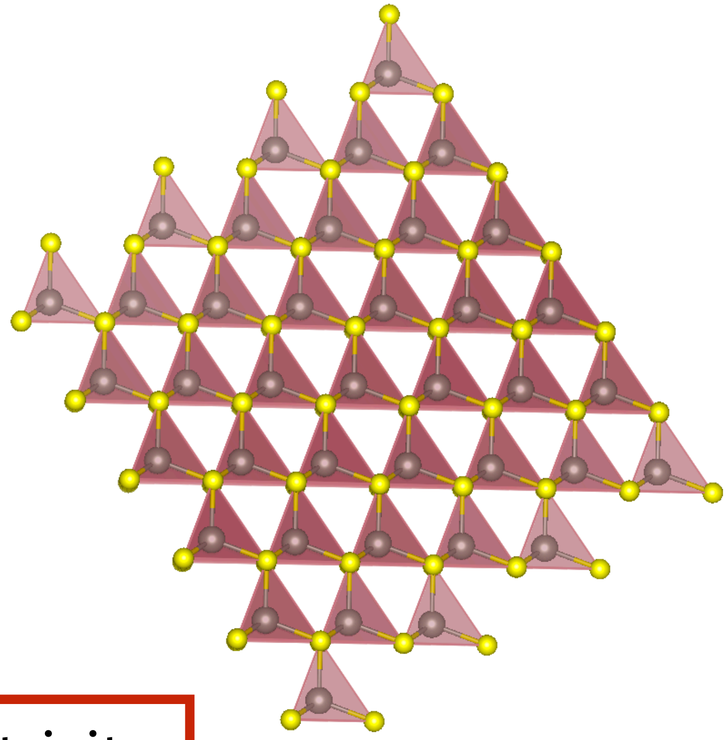
noncentrosymmetric crystal

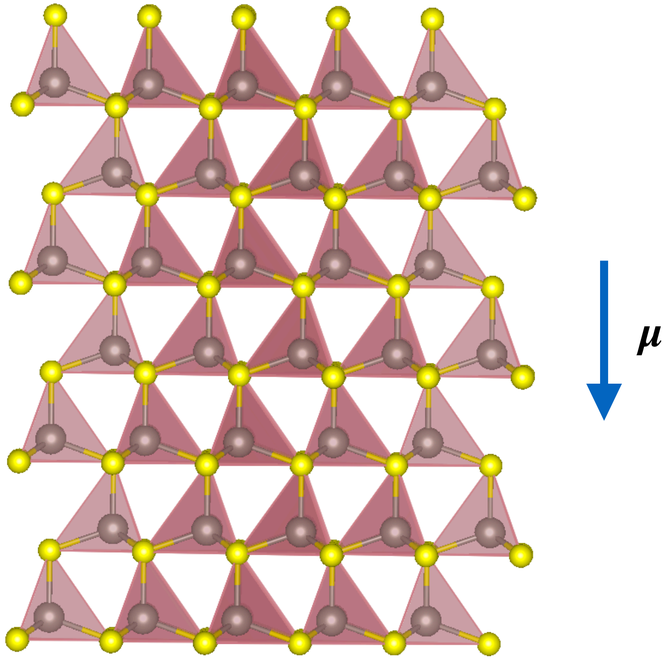
non-polar

non-polar

polar





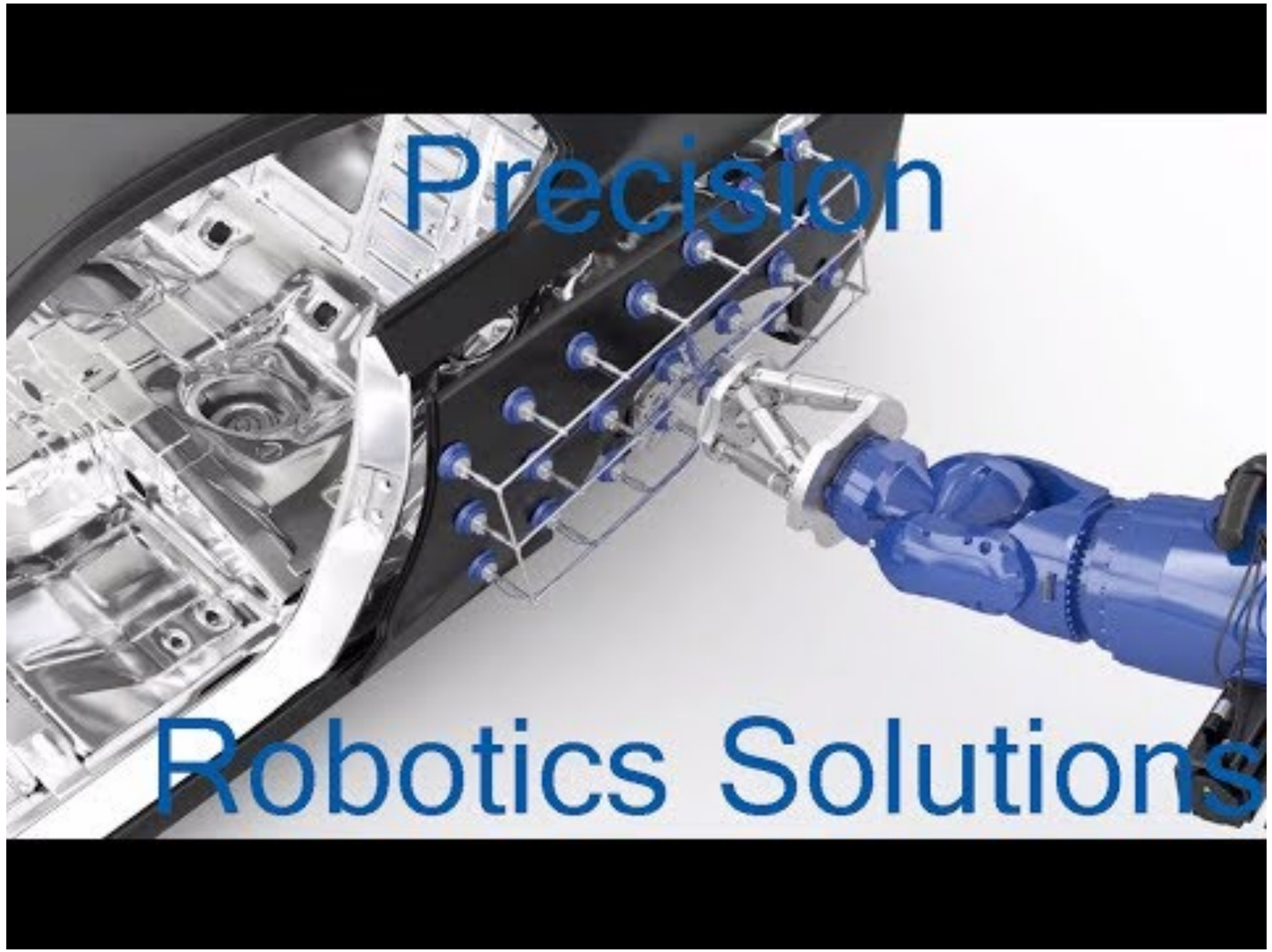


no pyroelectricity

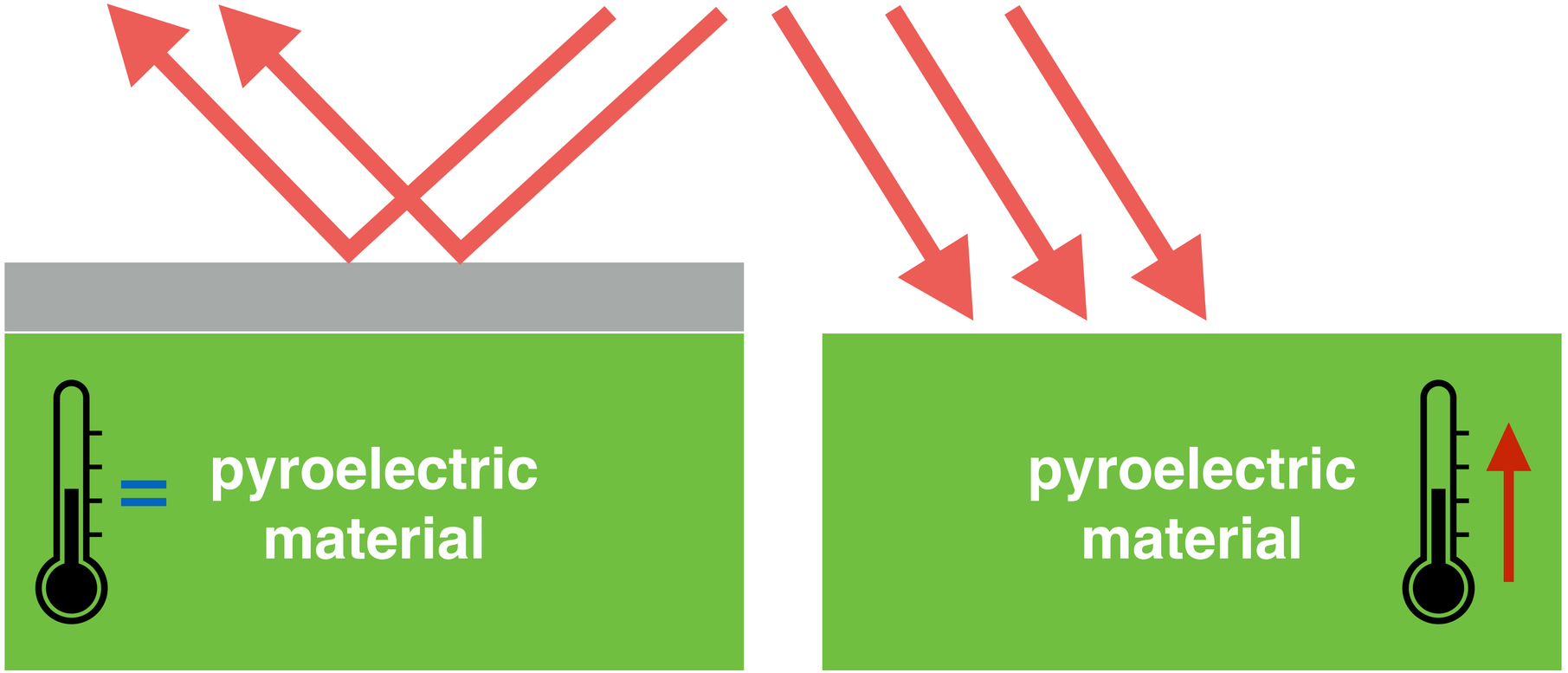
pyroelectricity

Applications of piezoelectricity: energy harvesting

Applications of piezoelectricity: hexapods



Applications of pyroelectricity: infrared detector



e.g. $LiTaO_3$

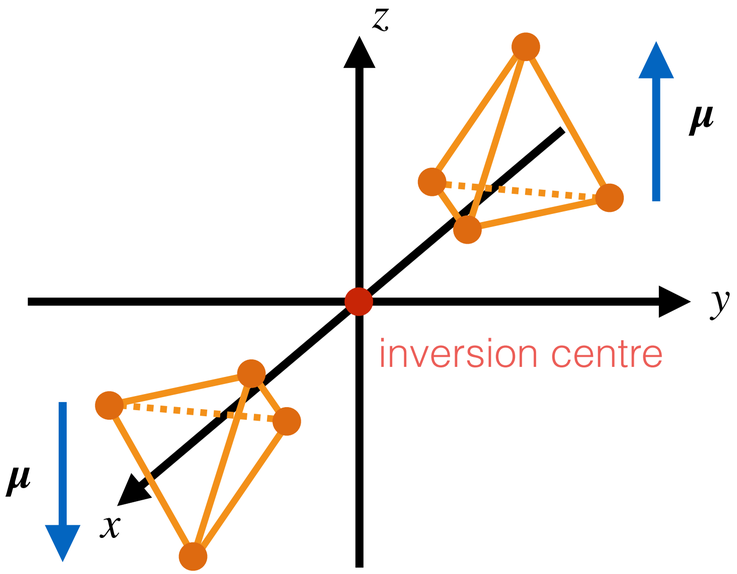
centrosymmetric crystal

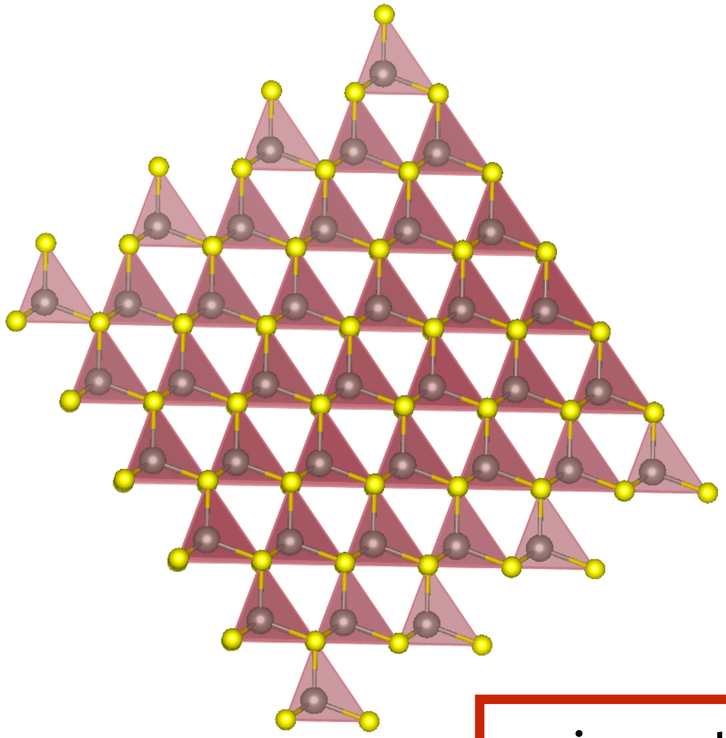
noncentrosymmetric crystal

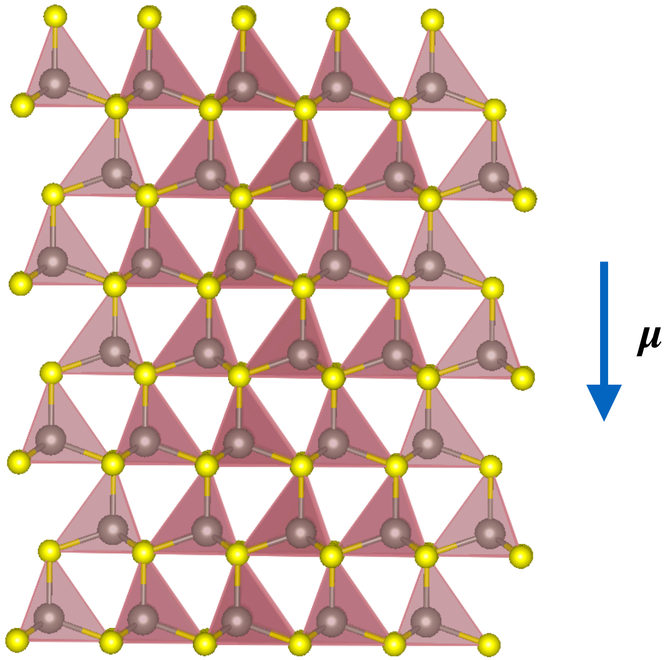
non-polar

non-polar

polar







no piezoelectricity

piezoelectricity*

* Cubic crystal class 432 exception

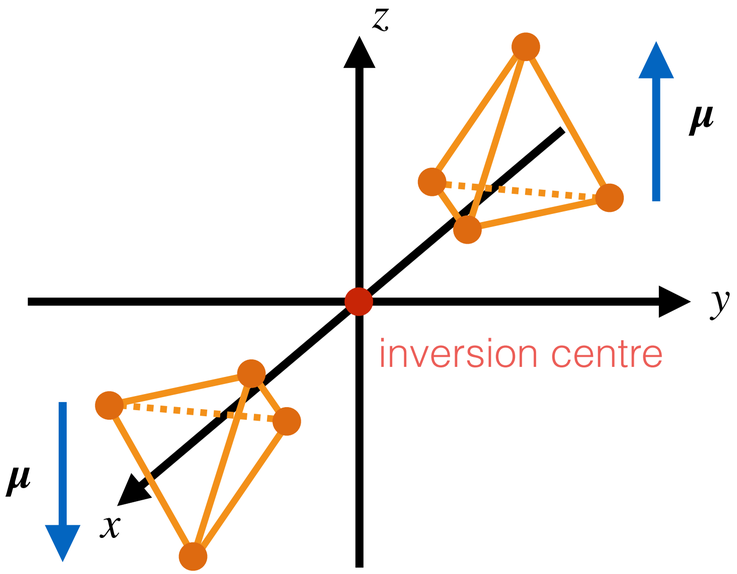
centrosymmetric crystal

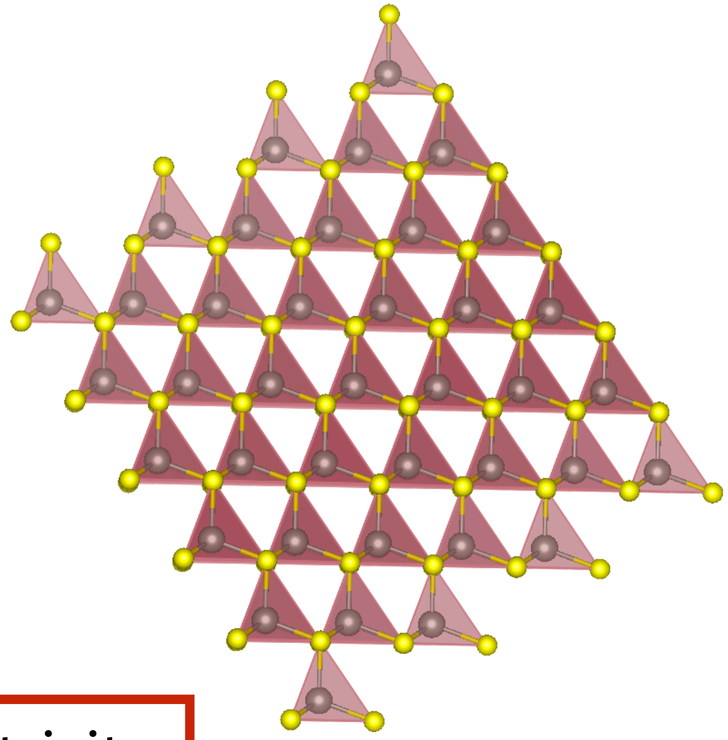
noncentrosymmetric crystal

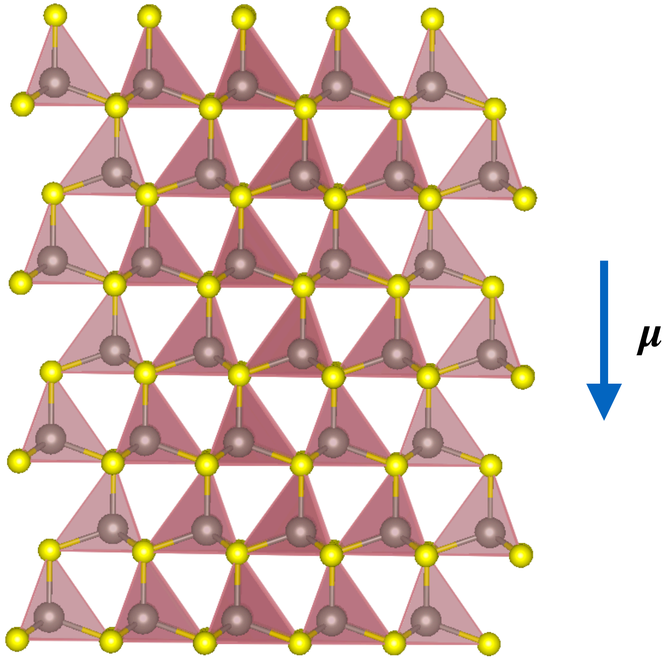
non-polar

non-polar

polar







no pyroelectricity

pyroelectricity