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<td>Mon.</td>
<td>4.1-5</td>
<td>Atomic nature of matter / springs</td>
<td>RE 4.a EP 3, HW3: Ch 3 Pr’s 42, 46, 58, 65, 72 &amp; CP*</td>
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<td>Stress, Strain, Young’s Modulus, Compression,</td>
<td>RE 4.c laptop, smartphone...</td>
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<td>Lab</td>
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<td>Sound</td>
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* Uses $G = 6.7 \times 10^{-11} \text{ N m}^2/\text{kg}^2$
The Atomic “hypothesis” (p. 139)

- All matter consists of atoms, whose typical radius is about $1 \times 10^{-10}$ m.
- Atoms attract each other when they are close to each other but not too close.
- Atoms repel each other when they get too close to each other.
- Atoms in solids, liquids, and gases keep moving even at very low temperatures.
A 180×190 Å² Image of the Pt(001)-hex reconstructed surface taken with a custom Scanning Tunneling Microscope at Aarhus University’s Scanning Probe Microscopy lab. The dark spot near the center is a single, missing atom.
Condensed Matter / Surface Science

Hex Reconstruction of Pt(001) Surface

- Platinum Crystal
  - Unit Cell
  - Bulk
Condensed Matter / Surface Science
Hex Reconstruction of Pt(001) Surface

- Platinum Crystal
  - Unit Cell
  - Bulk
  - Cleaved (001) Surface
  - Reconstructed (001) Surface
Condensed Matter / Surface Science

- Platinum Crystal
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Hex Reconstruction of Pt(001) Surface
A 180×190 Å² Image of the Pt(001)-hex reconstructed surface taken with a custom Scanning Tunneling Microscope at Aarhus University’s Scanning Probe Microscopy lab. The dark spot near the center is a single, missing atom.
Pair of atoms rotating
Pair of atoms traveling
Ball-Spring Model

$F = -k(L - L_0)$

Molecule

Solid
Atomic separation

\[
\frac{M_{\text{total}}}{Vol_{\text{total}}} = \text{density} = \frac{m_{\text{atom}}}{Vol_{\text{atom}}} = \frac{m_{\text{atom}}}{d^3} \Rightarrow d = \left( \frac{m_{\text{atom}}}{\text{density}} \right)^{\frac{1}{3}}
\]

\[
m_{\text{atom}} = \text{a.m.u.} * m_{\text{nucleon}} = \text{a.m.u.} * 1.7 \times 10^{-27} \text{ kg}
\]

\[
m_{\text{atom}} = \text{a.m.u.} * \left( \frac{1 \text{kmole}}{6.02 \times 10^{26} \text{ atom}} \right)
\]
Example: separation of Si atoms

One mole of silicon \((6 \times 10^{23} \text{ atoms})\) has a mass of 28 grams. The density of silicon is 2.33 grams/cm³. What is the typical separation of a silicon atom (i.e., ~ their diameters) assuming their arrangement cubically?
Wires as Masses on Parallel and Series Springs
\[ |F| = k_{ser} \Delta s \]

\[ |F| = k_{ser} (\Delta s_1 + \Delta s_2) \]

\[ |F| = k_{ser} \left( \frac{|F|}{k_1} + \frac{|F|}{k_2} \right) \]

\[ 1 = k_{ser} \left( \frac{1}{k_1} + \frac{1}{k_2} \right) \]

\[ \left( \frac{1}{k_1} + \frac{1}{k_2} \right)^{-1} = k_{ser} \]

\[ |F| = k_{ser} \Delta s \]
You hang a 1 kg mass from a spring, which stretches 0.4 m. You link the spring end to end with another identical spring, and hang a 1 kg mass from the linked springs. How much does this longer spring stretch?

a. 0.16 m
b. 0.2 m
c. 0.4 m
d. 0.8 m

Q4.5.a: Springs in “series”

You hang a 1 kg mass from a spring, which stretches 0.4 m. You link the spring end to end with another identical spring, and hang a 1 kg mass from the linked springs.

\[
\left( \frac{1}{k_1} + \frac{1}{k_2} \right)^{-1} = k_{ser}
\]
Special case: *Identical* Springs in Series

**Identical Springs 1&2**

\[
\begin{align*}
k_{ser} &= \left( \frac{1}{k_1} + \frac{1}{k_1} \right)^{-1} \\
k_{ser} &= \frac{1}{\left( \frac{1}{k_1} + \frac{1}{k_1} \right)} \\
k_{ser} &= \frac{1}{\frac{1}{k_1}} (2) \\
k_{ser} &= \frac{k_1}{2}
\end{align*}
\]

If 3, 4, ..., \(N_{ser}\) identical springs in series:

\[
k_{ser} = \frac{k_1}{N_{ser}}
\]

The more springs in series, the less stiff
Q4.5.b: Springs in “series”

A short spring has a stiffness of 20 N/m. You link 4 of these springs end to end to make a longer spring. What is the stiffness of the longer spring?

- a. 0.2 N/m
- b. 5 N/m
- c. 20 N/m
- d. 80 N/m

\[ k_{ser} = \frac{k_1}{N_{ser}} \]
Springs in Parallel

|F_1| = k_1 Δs
|F_2| = k_2 Δs
|F| = k_{par} Δs

k_{par} Δs = |F|

k_{par} Δs = k_1 Δs + k_2 Δs
k_{par} Δs = (k_1 + k_2) Δs
k_{par} = (k_1 + k_2)
Special case: *Identical* Springs in Parallel

$$k_{par} = (k_1 + k_1)$$

If 3, 4, ..., $N_{par}$ identical springs in parallel:

$$k_{par} = N_{par} k_1$$

The more springs in parallel, the stiffer
Q4.5.c: Springs in “parallel”

You hang a 1 kg mass from a spring, which stretches 0.4 m. You place a second identical spring beside the first, so the 1 kg mass is now supported by two springs.

How much does each spring stretch?

a. 0.2 m  

b. 0.4 m  

c. 0.5 m  

d. 0.8 m
Q4.5.d: Springs in “parallel”

A short spring has a stiffness of 20 N/m. You use 4 of these springs side by side to support a mass. What is the stiffness of the 4 side-by-side springs, considered as one effective spring?

a. 0.2 N/m  
b. 5 N/m  
c. 20 N/m  
d. 80 N/m
Wires as Masses on Identical Parallel and Series Springs
The Micro-Macro Connection: Stiffness for springs in series *and* in Parallel

Area = $N_{par} \times d^2_{bond}$

Length = $N_{ser} \times d_{bond}$

$N_{ser} = \frac{L}{d}$

$N_{par} = \frac{A}{d^2}$

$F = k_{tot} \Delta L$

$F = \left( \frac{N_{par}}{N_{ser}} \right) k_1 \Delta L = \left( \frac{A}{d \cdot L} \right) k_1 \Delta L$

$k_{total} = \left( \frac{A}{d \cdot L} \right) k_1$
Q4.6.d: Wires

You hang a 10 kg mass from a copper wire, and the wire stretches by 8 mm. Now you hang the same mass from a second copper wire, whose cross-sectional area is half as large (but whose length is the same).

What happens?

a) The second wire stretches 4 mm
b) The second wire stretches 8 mm
c) The second wire stretches 16 mm
Q4.6.e: Wires

You hang a 10 kg mass from a copper wire, and the wire stretches by 8 mm.
Now you hang the same mass from a second copper wire, which is twice as long, but has the same diameter. What happens?

a) The second wire stretches 4 mm
b) The second wire stretches 8 mm
c) The second wire stretches 16 mm
Spring in Series & Parallel Rephrased

Stress, Strain, and Young’s Modulus

\[ F = k_{total} \Delta L \]

\[ F = \left( k_{atomic} \frac{A}{dL} \right) \Delta L \]

regroup

Microscopic details

Macroscopic measurables

\[ \Delta \equiv \text{Young's Modulus} \]

\[ F = Y \frac{A \Delta L}{L} \]

\[
\left( \frac{F}{A} \right) = Y \left( \frac{\Delta L}{L} \right)
\]

Stress

force transmitted per area (pressure)

Strain

stretch per length (fractional stretch)

1/Y = slope

From counting series and parallel

\[ \Delta \]

springy

breaking

\[ \text{Strain}(10^{-3}\text{m/m}) \]

\[ \text{Stress}(10^8\text{N/m}^2) \]
Two wires with equal lengths are made of pure copper. The diameter of wire A is twice the diameter of wire B.

When 6 kg masses are hung on the wires, wire B stretches more than wire A.

\[ Y = \frac{F/A}{(D/L)}/L \]

You make careful measurements and compute Young's modulus for both wires. What do you find?

1) \( Y_A > Y_B \)
2) \( Y_A = Y_B \)
3) \( Y_A < Y_B \)
Example: You hang a heavy ball with a mass of 14 kg from a silver rod 2.6 m long by 1.5 mm by 3.1 mm. You measure a stretch of the rod, and find that the rod stretched 0.002898 m. Using these experimental data, what value of Young’s modulus do you get?
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<td>4.11-12; 14-15 Sound in Solids, Analytical Solutions</td>
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