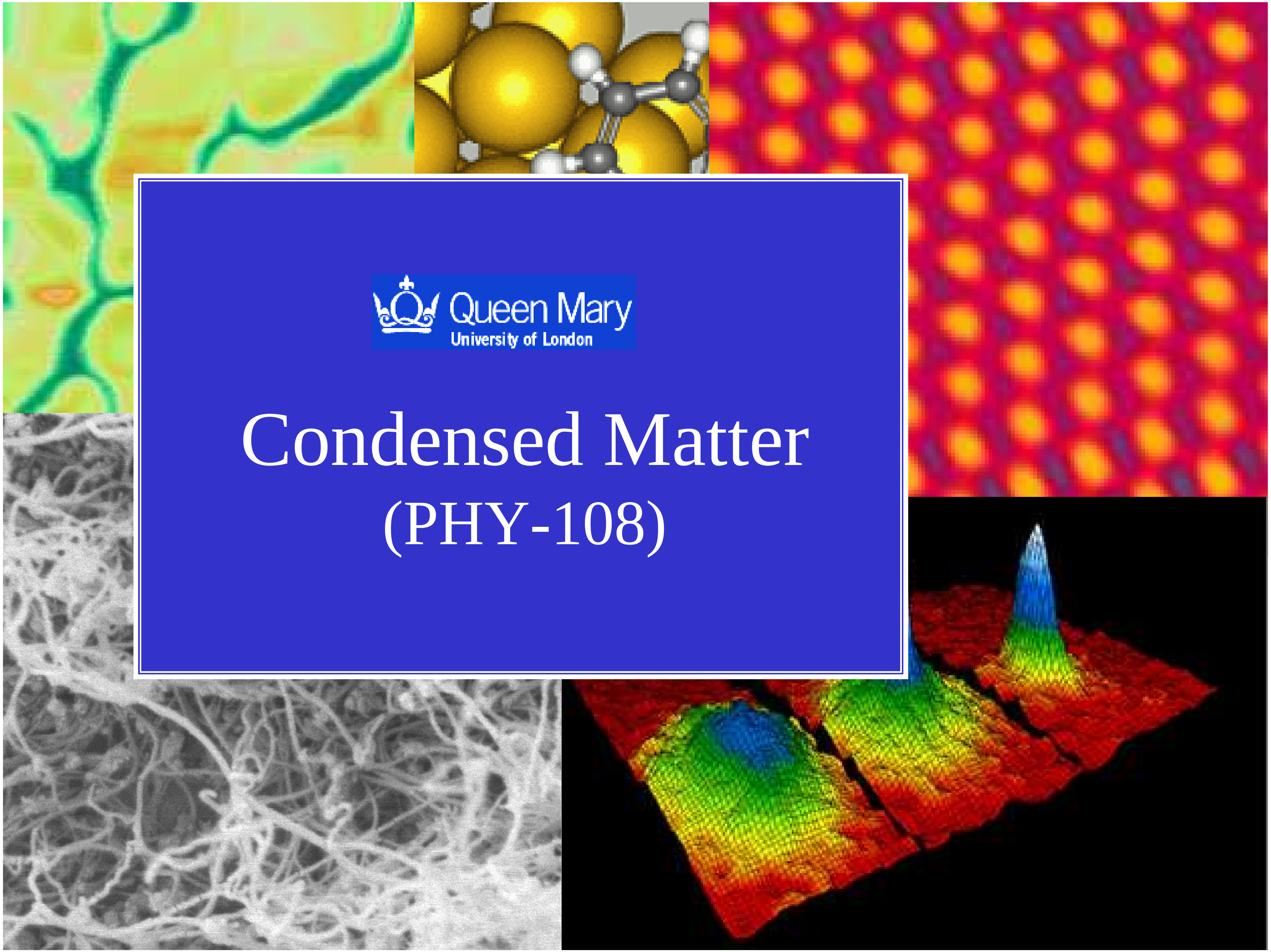


Queen Mary
University of London

Condensed Matter
(PHY-108)

Why Condensed Matter Physics?

"All Nature as it is in itself consists of two things – bodies and the vacant space in which the bodies are situated and through which they move in different directions"

TITUS LUCTRETIUS CARUS   99-55 B.C.

• Relevant to our lives, we can observe it and we can interact with it.
•More generally, the field of ***condensed matter physics*** deals with systems composed of a very large number of building blocks that can not be regarded as independent, i.e. whose mutual interactions are essential to describe the properties of the system
• Thus the term ***condensed matter*** includes all states of matter (solid, liquid, gas, plasma), plus more exotic states like the Bose-Einstein Condensate

• CM will provide the basis for the physical description of solids, liquids, gases, and other exotic states for Physics based programmes. The Year 3 suggested course unit ‘Solid State Physics’ follows some of the themes in CM

Course details

- **3 Lectures per week**

  Wed 10:00-11:00 Francis Bancroft: David Sizer LT
  Wed 12:00-13:00 Francis Bancroft: David Sizer LT
  Fri 13:00-14:00 Francis Bancroft: David Sizer LT

- **Exercises**

  1 per week
  Handed out on Wednesday
  Hand in by 16:00 on the following Wednesday (Floor 1 hand-in pigeonholes)
  Minimum of 75% hand-in rate expected
  Marks posted against Student Number on CM Home Page
  Scripts returned and solutions discussed in Fri 13:00-14:00 lecture
  20% of total mark for CM

- **Mid-term Test**

  Week 8 (after Reading Week)

  45 minutes

  Marks posted against Student Number on CM Home Page

  10% of total mark for CM

- **Final Examination**

  2 h 30min in Summer Exam Period

  2 hour Revision Lecture before Exam Period

  CM is a new course, but there are some past exam questions

  70% of total mark for CM

- **Attendance**

  Minimum of 75% expected

  Absence notification by web:

  http://www.ph.qmul.ac.uk/smpinput?absence

  or inform Advisor

- **Revision**

  There will be a 2 hour revision lecture immediately before the examination period when we will go over any topics in CM and practise exam questions

- **Questions**

  Please ask questions at ANY TIME in class or with me individually during the office hour

- **Plagiarism**

  There are strict college rules against plagiarism (i.e. passing off someone else's work as your own) – SEE STUDENT HANDBOOK

Course Information

- **Course Organiser: Dr A. Sapelkin**

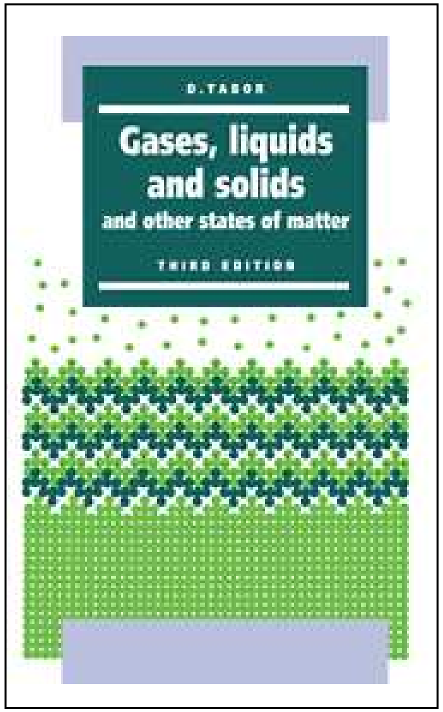
  Room 120A
  a.sapelkin@qmul.ac.uk
  Office hour: Friday 11:00-12:00

- **Deputy: Dr. J. Dennis**

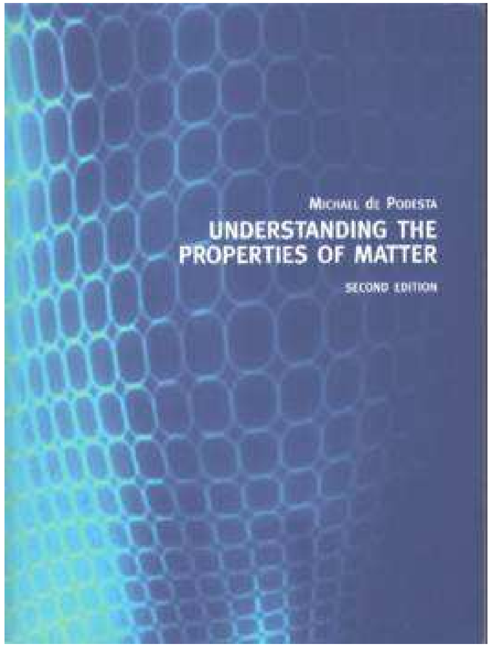
  Room 120
  j.dennis@qmul.ac.uk
  Office hour: ??

All information will be available on the CM Home Page:
Route: Physics Home Page (www.ph.qmul.ac.uk) Student Handbook Index to BSc Courses - CM Home Page

Books



Tabor, D.
Gases, Liquids and Solids:
and Other States of Matter
Cambridge University Press, (3rd edition, 1991)
ISBN 0-521-40667-6 **(7 copies in library)**
New £22.99 (Amazon)
Used £9.95 (Amazon)



de Podesta, M.
Understanding the Properties of Matter
Taylor & Frances, (2nd edition, 2001)
ISBN 0-415-25788-3 **(1copy in library)**
New ~£24, http://www.physicsofmatter.com/

Other Book

Flowers, B.H., Mendoza, E.
Properties of Matter
(4 copies in library)

These notes

These notes will be posted on the CM Home Page before lectures
Please download them

These notes alone will not be enough to pass the exam, you need to attend lectures, complete the weekly exercises, and do some reading.

Course Content

- **Interatomic Forces**

  Crystal lattice, van der Waals, ionic, covalent and hydrogen bonding

- **Properties of Solids Related to Interatomic Forces**

  Binding energy, surface energy, the cubic lattice, elastic properties, heat capacity, an introduction to phonons

- **The Liquid State**

  Loss of order, radial distribution function, macroscopic properties of viscosity and compressibility, molecular fluids.

- **Gases**

  ideal gas equation of state, real gases, van der Waals model, phase coexistence, the phase diagram, liquid/gas phase transition, phase diagrams

- **Transport Properties**

  Diffusion, electrical conductivity, thermal conductivity

- **Dielectric properties**

  Electronic energy states, band gap

- **Introduction to Magnetism**

We will use the Friday lecture to do worked examples of exam level questions as well as to go through the solutions to the weekly problems

Note about Mathematics and Thermal Physics

- **Maths**

  All the maths content of CM should be covered in MT1. If there is any difficulty please raise the problem in class

- **Thermal Physics**

  Some of the concepts in CM will be covered in Thermal and Kinetic physics (PHY-214) in Semester 3

Standards and Units

•Any physical quantity that can be quantified has been assigned a standard ***UNIT***. In many cases physical quantities are so fundamental they can only be defined from ***empirical knowledge*** (i.e. by measurement)

• The standard system of units is known as ***Système International (SI)***

Système International (SI Units)

Base quantity	Name	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

SI Units Definitions

TIME (Seconds (s)) – the definition of the second is based on the atomic clock, which uses the energy difference between 2 states of the caesium atom. One second is defined as the time for 9,192,631,770 cycles

LENGTH (Metres (m)) – defined as the distance travelled by light in a vacuum in 1/299,792,458 seconds

MASS (Kilogram (Kg)) – defined as the mass of a particular cylinder of platinum-iridium alloy

Unit Prefixes

Prefix	**Symbol**	**Scale**
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
Kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Physical constants

Electronic charge	e	$1.60(10^{-19})$ C
Free space permittivity	ε_0	$8.88(10^{-12})$ F.m^{-1}
Plank constant	h	$6.62(10^{-34})$ J.s
Rest mass of electron	m_e	$9.11\ (10^{-31})$ kg
Rest mass of proton	m_p	$1.672(10^{-27})$ kg
Rest mass of neutron	m_n	$1.674(10^{-27})$ kg
Avagadro's number	N_A	$6.022\ (10^{23})$ mol^{-1}
Molar gas constant	R	8.315 J. mol^{-1}.K^{-1}

Symbols Used in CM

P	Pressure	F	Force
T	Temperature	r	Distance
V	Volume	q	Charge
E, ε	Energy	ε_0	Free space permittivity
Q	Heat absorbed	n	Coordination number
W	Work	m	Mass
p	Momentum	M	Molar mass

But…

Angstrom 1 Å = 10^{-10} m = 0.1 nm (~ size of one atom)

Atmosphere 1 atm = 1.013 (10^{5}) Pa (Standard Pressure)

Macroscpic energy in Joules (J)
Microscopic energy in electron-Volts (eV)

1 eV=(electronic charge)(1Volt) = 1.6 (10^{-19}) J

• Physicists sometimes use other systems of units for convenience: we will go into detail when we encounter them

Atomic Mass Units

Relative mass unit. Basic unit taken to be one twelfth of the mass of a single atom of ^{12}C the most abundant carbon isotope

$$1\ \text{amu} = \frac{1}{12} M_{^{12}\text{C}} = \frac{1}{12}(1.9926)(10^{-26})\text{kg} = 1.66(10^{-27})\text{kg}$$

For molecular masses we quote RELATIVE MOLECULAR MASS

$$M_\text{r} = 12.\left\{\frac{\text{mass of one molecule of substance}}{\text{mass of }^{12}\text{C}}\right\}$$

$$\text{Mass of one molecule} = M_\text{r}\left(\frac{M_{^{12}\text{C}}}{12}\right) = M_\text{r}$$

Most molecular masses are close to **integral** values in amu so we often round these to the nearest integral value

e.g. ${M_r}_{H_2}$=2.016 amu ≈ 2 amu

Given a molecule of relative mass M_r we define

1 mole = 1 mol = M_r gm
1 kmole = 1 kmol = M_r kg

e.g. 1 mole of H_2 gas has mass 2.016 gm ≈ 2 gm

You must specify the molecule to specify how much is in a mole

e.g. 1 mole of atomic hydrogen ≈ 1 gm
1 mole of carbon dioxide ≈ 44 gm

IMPORTANT FACT: 1 mole of any molecular substance contains the same number of molecules, called AVAGADRO number, N_A

$$N_A = 6.022(10^{23})\ \text{mol}^{-1}$$

$$1\ \text{gm} = (1\ \text{mole})\ N_A\ \text{amu}$$

Relative molecular mass: DO NOT CONFUSE WITH ATOMIC MUMBER

IA	IIA	IIIB	IVB	VB	VI B	VII B	VIII B
1 H							4 He
7 Li	9 Be	11 B	12 C	14 N	16 O	19 F	20 Ne
23 Na	24 Mg	27 Al	28 Si	31 P	32 S	35.5 Cl	40 Ar

Key Concept: Orders of Magnitude

1 light year=9.5 Tm

1 m
1 μm
1 nm=10 atoms

Condensed Matter deal with bodies on the scale of 1m - 1 nm

Decreasing size

?
Universe
Galactic clusters
Galaxies
Stars Planets
Comets Asteroids
Dust
Molecules
Atoms
Nuclei Photons Electrons
Z^0 $W^{\pm}$
Quarks Gluons
Strings
?

Greek alphabet

Α α Alpha	Β β Beta	Γ γ Gamma
Δ δ Delta	Ε ε Epsilon	Ζ ζ Zeta
Η η Eta	Θ θ Theta	Ι ι Iota
Κ κ Kappa	Λ λ Lambda	Μ μ Mu
Ν ν Nu	Ξ ξ Xi	Ο ο Omicron
Π π Pi	Ρ ρ Rho	Σ σ Sigma
Τ τ Tau	Υ υ Upsilon	Φ φ Phi
Χ χ Chi	Ψ ψ Psi	Ω ω Omega

http://en.wikipedia.org/wiki/Greek_alphabet

Key Concept:Microscopic/Macroscopic

MACROSCOPIC – applies to the average large-scale behaviour of a large collection of identical building blocks

MICROSCOPIC – applies to the attributes and forces that act on the building blocks

Key Concept: Energy Conservation

ENERGY – associated with the fundamental building blocks

ENERGY CONSERVATION–empirical fact at the macroscopic level: we can attribute an energy E (often called internal energy) that is conserved. This can be written

$$\Delta E = E(after) - E(before) = Q + W$$

Q=HEAT ABSORBED by the sample

W=WORK done by the sample

FIRST LAW OF THERMODYNAMICS: energy may be transformed but is never created or destroyed

Key Concept: Equilibrium

Isolate a 'lump' of matter from external influence. The lump (or system) is said to be in **EQUILIBRIUM** when:

- Macroscopic properties like P and T are **time independent**
- There are no flows of **heat** or **energy** or **momentum (*p*)** in the system as seen macroscopically

In equilibrium macroscopic parameters, such as *P*, *T*, *V*, and *E*, are enough to uniquely describe the system and are uniform throughout the system

A disturbance will cause non-uniform *P* and *T* and the system will set up internal flows to re-establish equilibrium: the rate of recovery will depend on the properties of the building blocks

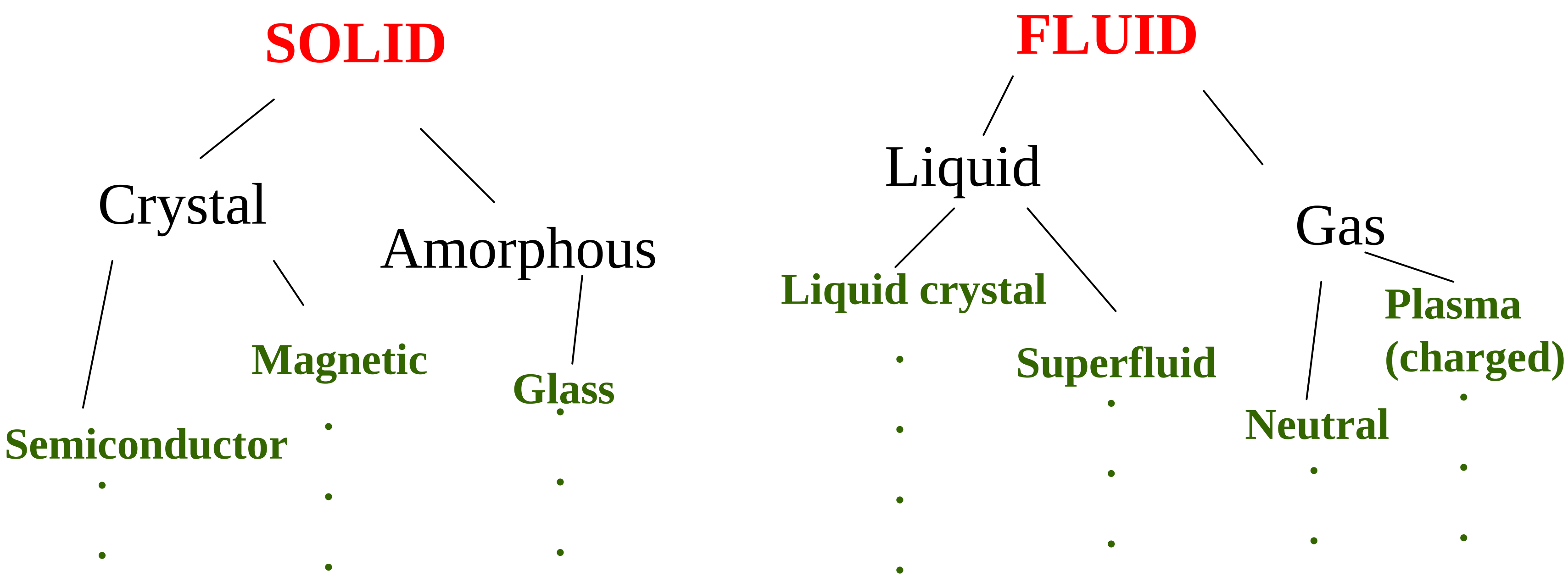
Key Concept: Microscopic Energy

MICROSCOPIC ENERGY – at the molecular level:

$$E = \text{Potential Energy} + \text{Kinetic Energy}$$

At low T, E is dominated by potential energy arising from **molecular forces**

Key Concept:
‘Phases’ or ‘States’ of Matter



A substance can undergo a **phase transition** by altering *P* or *T*
e.g. melting, evaporation, sublimation, magnetisation…

Key Concepts:Order & Attributes

SOLID | **LIQUID** | **GAS**

Crystal | Amorphous

SOLID	LIQUID	GAS
(Ordered Structure over long range)	**Short rage order**	**Disordered**
	More dense	**Less dense**
	Has natural surface & volume (surface tension)	**No fixed surface & volume**
Elasticity Rigidity		

Viscosity & flow properties (Liquid ↔ Gas)

Compressibility (Solid ↔ Gas)

Summary

- Introduction
- Units
- Keys concepts:

Order of magnitude

Microscopic/macroscopic

Energy conservation

Equilibrium

Microscopic energy

Phases of matter

Order

Attributes: solid, liquid, gas

Next Topic: Interatomic Forces