Appendix F:

More interesting Points

- Compare liquid with solid phase

liquid	solid
has continuous rotational and translational symmetries	does not have continuous rotational and translational symmetries

Solid is a phase with broken symmetry

- In the broken symmetry phase (i.e. solid), low-energy excitations do not have an energy gap, i.e. $\omega(q)$ has the property that $\omega \to 0$ as $q \to 0$ (c.f. acoustic branches).

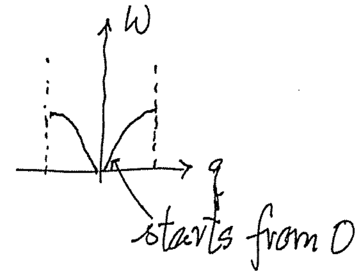
This is related to something called the "Goldstone bosons" in spontaneous symmetry breaking.

The Goldstone Theorem

When there is a broken continuous symmetry at a phase transition, there should exist in the ordered state of the system+ a collective mode, an excitation, with gapless energy spectrum (i.e., energy that starts continuously from 0).

c.f. phonon dispersion relation

(phonon = collective excitations)



+Strictly speaking, no long-range interaction is assumed.

Universal Behaviour

- From $\omega(\vec{q})$ and 3D, we have

$$C_V(T) \sim T^3 \text{ at low temperatures}$$

This is observed almost universally!

[Thus, this is a feature that does not depend on the microscopic features, e.g. atoms, lattice type, basis, lattice constant, etc.]

All it takes[+] is $\omega(q) \sim q$ as $q \to 0$
and 3D!

It is the study of universal behavior that makes the subject of physics special!

[+] See Ch. VII.