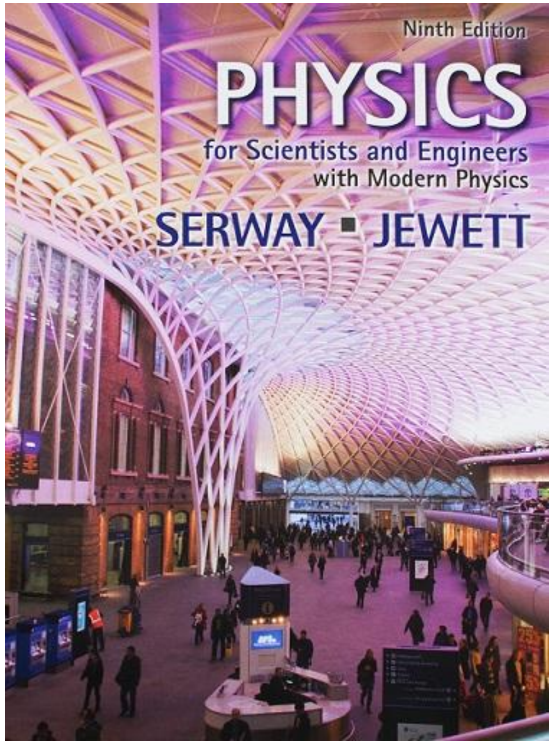
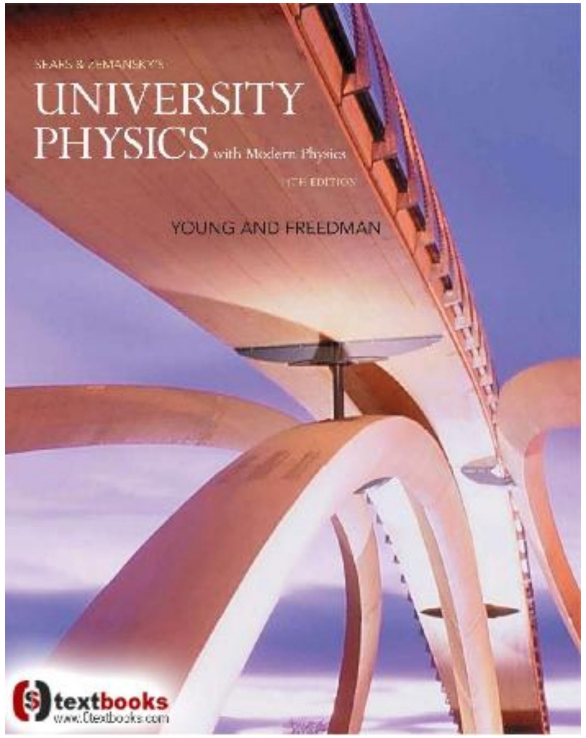
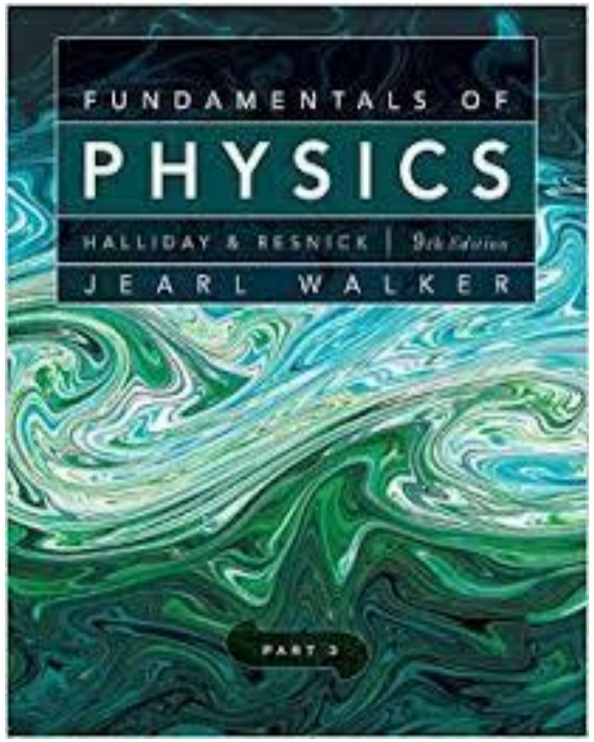
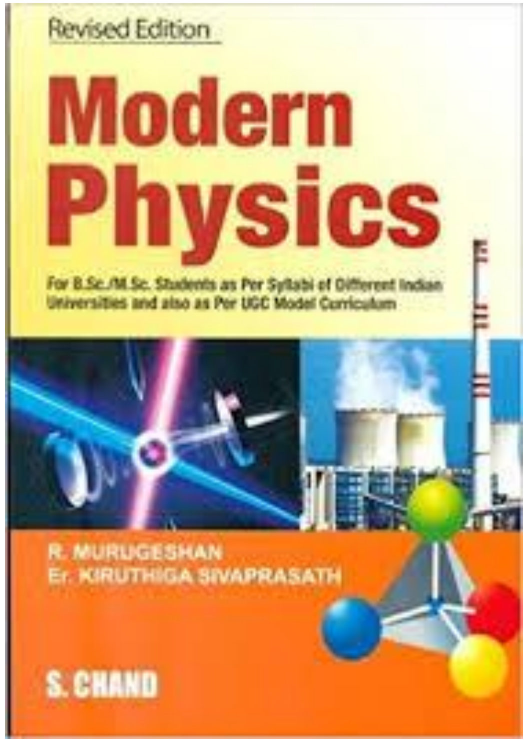
PHYSICS

General Physics II (PHYS 102)









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Course Outline

- Raman Effect and its Quantum Treatment
- Superconductivity

Raman Effect

Raman Effect

- While studying the scattering of light, Raman found that when a beam of monochromatic light was passed through organic liquids such as benzene, toluene etc., the scattered light contained other frequencies in addition to that of the incident light. This is known as **Raman Effect**.

- Raman Shift:

$$\Delta \upsilon = \upsilon_i - \upsilon_s$$

υ_s: frequency of the scattered photon by a given molecular species

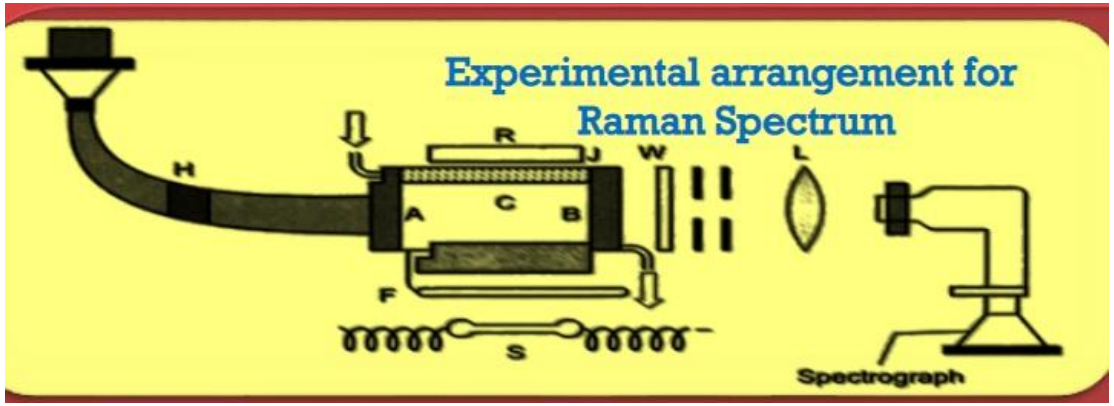
υ_i: frequency of the incident photon

When

(i) $\Delta \upsilon$ is positive, $\upsilon_s < \upsilon_i$: Raman spectrum is said to consists of *stokes lines*.

(ii) $\Delta \upsilon$ is positive, $\upsilon_s < \upsilon_i$: Raman spectrum is said to consists of *anti-stokes lines*.

Experimental Study of Raman Effect



The scattering liquid is taken in a horn like glass tube called Raman tube. One end of the tube is closed with an optically plane glass plate constituting a window **W**, for scattered light to emerge. The other end of the tube is drawn out to the shape of a horn (**H**) and its outside is blackened to provide a contrasting background, suitable for observation. The liquid is illuminated by mercury arc lamp **S**. **R** is a metal reflector to increase the intensity of illumination further. To prevent overheating, the tube is surrounded by a jacket **J** through which cold water circulate. **F** is a filter and it filters and permits only highly monochromatic light. The convex lens **L** is arranged in front of window focuses and directs the scattered radiation upon the slit of spectroscope. The light is scattered in a transverse direction and is observed through a spectroscope.

Quantum Theory of Raman Effect:

- Raman effect is due to the interaction between a light photon and a molecule of the scatterer.
- Let us consider a molecule in its initial state E_i and is exposed to incident photon of frequency υ_i .

  The absorption of this incident photon would raise this molecule to a level in which its energy is $(E_i + h\upsilon_i)$.
- Now suppose it returns to a level of energy E_f , by loosing energy $h\upsilon_s$ and emitting (scattered) photon having observed frequency υ_s .
- It follows then,

$$(E_i + h\upsilon_i) - h\upsilon_s = E_f$$

$$\Rightarrow \upsilon_i - \upsilon_s = \frac{E_f - E_i}{h}$$

$$\therefore \Delta\upsilon = \frac{E_f - E_i}{h} \quad ....(1) \quad \text{and} \quad \upsilon_s = \upsilon_i - \left[\frac{E_f - E_i}{h}\right] \quad ....(2)$$

- Three cases may arise:

(i) If $E_f = E_i$, then $\Delta\upsilon = 0 \Rightarrow \upsilon_s = \upsilon_i$. This represents the unmodified line.

(ii) If $E_f > E_i$, then $\Delta\upsilon$ is positive, so $\upsilon_s < \upsilon_i$. This represents the stokes lines.

(iii) If $E_f < E_i$, then $\Delta\upsilon$ is negative, so $\upsilon_s > \upsilon_i$. This represents the antistokes lines.

Raman Effect

Quantum Theory of Raman Effect:

- **Figure R-1** shows Energy-level diagram showing the states involved in Raman spectra.

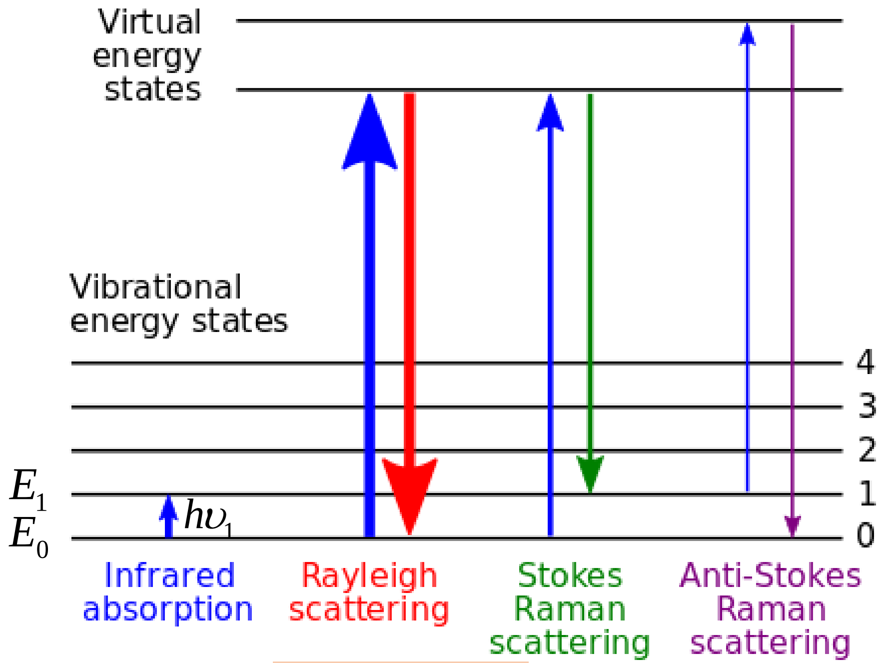


Figure R-1

From Eq. (2)

$$\upsilon_s = \upsilon_i - \left[\frac{E_f - E_i}{h}\right]$$

For stokes line:

$$E_i = E_0 \text{ and } E_f = E_1$$

$$\therefore \upsilon_s = \upsilon_i - \left[\frac{E_1 - E_0}{h}\right]$$

So, frequency of stokes line $\boxed{\upsilon_{st} = \upsilon_i - \upsilon_1}$ where, $\upsilon_1 = \dfrac{E_1 - E_0}{h}$

Frequency of emission infrared during the transition between the first two vibrational states

For antistokes line

$$E_i = E_1 \text{ and } E_f = E_0$$

$$\therefore \upsilon_s = \upsilon_i - \left[\frac{E_0 - E_1}{h}\right] = \upsilon_i + \left[\frac{E_1 - E_0}{h}\right]$$

So, frequency of anti-stokes line $\boxed{\upsilon_{ast} = \upsilon_i + \upsilon_1}$

Characteristics of Raman Effect:

- The Stokes lines are always more intense than antistokes lines.
- The Raman lines are symmetrically displaced about the parent line.
- The frequency difference between the modified and parent line represents the frequency of the corresponding infrared absorption line.

Superconductivity

- There is a class of metals and compounds whose resistance decreases to zero when they are below a certain temperature T_C , known as the critical temperature. These materials are known as **superconductors**.
- The electrical resistivity of many metals and alloys drops suddenly to zero when the specimen is cooled to a sufficiently low temperature. This phenomenon is called **superconductivity**.
- In 1911, Dutch physicist Kamerlingh Onnes discovered that the resistivity of mercury absolutely disappears at temperatures below about 4 K (**Figure S-1**).

  This phenomenon of **superconductivity** is of vast potential importance in technology because it means that charge can flow through a superconducting conductor without losing its energy to thermal energy.
- A superconductor is a material in which (below the maximum superconducting temperature) ,

$$R = 0, \text{ the magnetic filed } B = 0, \text{and } \chi_{\text{magnetic}} < 0$$

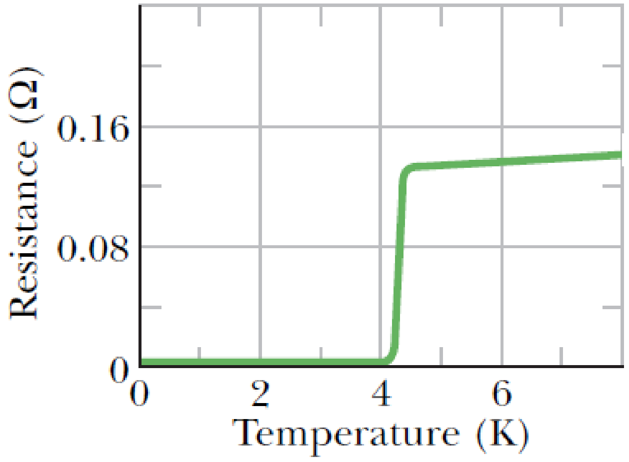


Figure S-1
The resistance of mercury drops to zero at a temperature of about 4 K.

The critical temperature is the temperature at which the electrical resistance of the material decreases to virtually zero.
The value of critical temperature is sensitive to chemical composition, pressure, and molecular structure. Copper, silver, and gold, which are excellent conductors, do not exhibit superconductivity.

PHYSICS OF ATOMS AND MOLECULES

Superconductivity

Meissner Effect

- When a specimen is placed in a magnetic field and is then cooled through the transition temperature for superconductivity, the magnetic flux originally present is ejected from the specimen.

This is called the **Meissner Effect**.

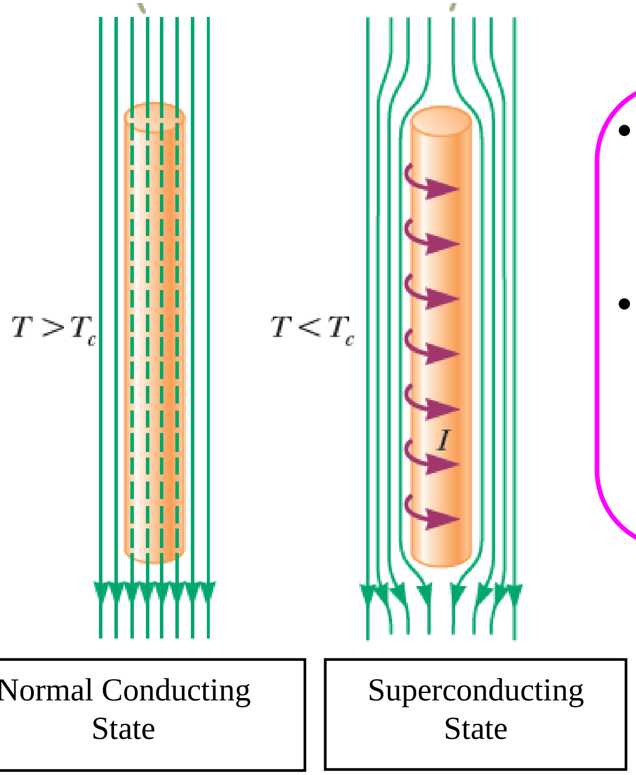


Figure S-2
A superconductor in the form of a long cylinder in the presence of an external magnetic field.

- A superconductor expels magnetic fields from its interior by forming surface currents
- Surface currents induced on the superconductor's surface produce a magnetic field that exactly cancels the externally applied field.

- The Meissner effect shows that a bulk superconductor behaves as if inside the specimen B = 0.
- We have,

Magnetic Induction

$$\vec{B} = \mu_0 (1 + \chi_m) \vec{H}$$

$$\Rightarrow 0 = \mu_0 (1 + \chi_m) \vec{H}$$

$$\Rightarrow 1 + \chi_m = 0$$

$$\because \boxed{\chi_m = -1}$$

↑

Magnetic susceptibility

- So the **Meissner effect** suggests that perfect diamagnetism is an essential property of the superconducting state.

Superconductivity

Meissner Effect

- Figure SM-I shows a homogeneous sphere of a superconducting material in a uniform applied magnetic field $\vec{B}_0$ at a temperature T greater than the critical temperature T_C .

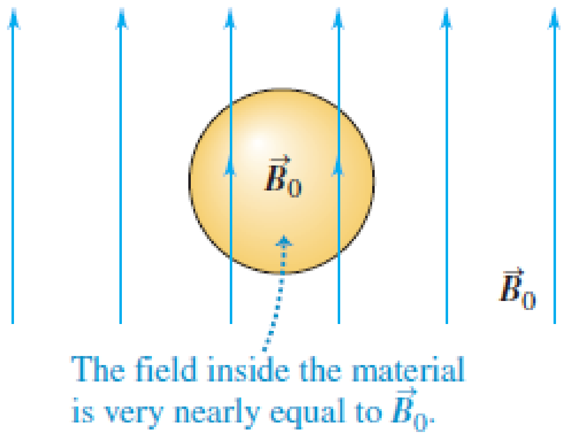
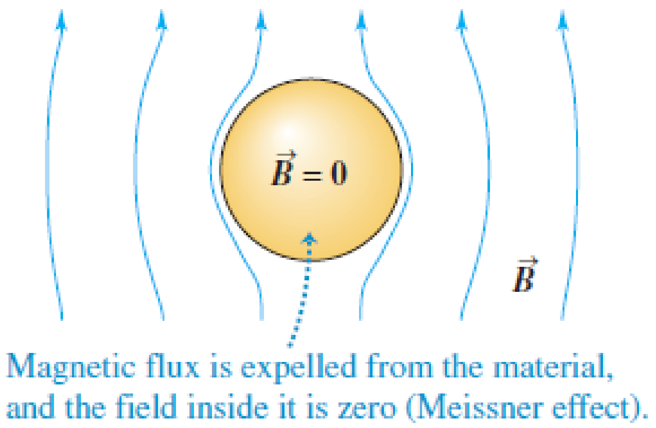


Figure SM-I
Superconducting material in an external magnetic field $\vec{B}_0$ at $T > T_C$

- Figure SM-2 shows a homogeneous sphere of a superconducting material in a uniform applied magnetic field $\vec{B}_0$ at a temperature T less than the critical temperature T_C.



The temperature is lowered to $T < T_C$, so the material becomes superconducting.

Superconductivity

Destruction of Superconductivity by Magnetic Fields

- A sufficiently strong magnetic field will destroy superconductivity.
- The critical value of the applied magnetic field for the destruction of superconductivity is denoted by $H_C(T)$ and is a function of the temperature.
- At the critical temperature the critical field is zero: $H_C(T_C) = 0$
- The variation of the critical field with temperature is given by

$$H_C(T) = H_C(0)\left[1 - \left(\frac{T}{T_C}\right)^2\right]$$

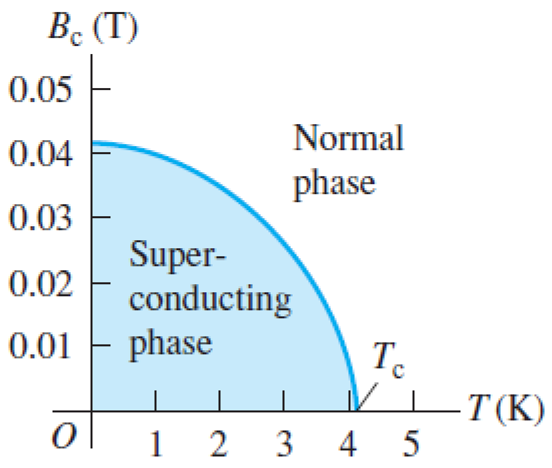


Figure S-1
Phase diagram for pure mercury, showing the critical magnetic field and its dependence on temperature. Superconductivity is impossible above the critical temperature. The curves for other superconducting materials are similar but with different numerical values.

Sample Problem

A superconducting tin has a critical temperature of 3.7 K in zero magnetic field and a critical field of 0.0306 T at 0 K. Find the critical field at 2 K.

Hint:

$$H_C(T) = H_C(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

$$\Rightarrow H_C(2\text{K}) = 0.0306\left[1 - \left(\frac{2}{3.7}\right)^2\right] = 0.0217\text{T}$$

Superconductivity

Nobel Prizes and Recent Research

- A successful theory for superconductivity in metals was published in 1957 by John Bardeen, L. N. Cooper (b. 1930), and J. R. Schrieffer (b. 1931); it is generally called BCS theory, based on the first letters of their last names. This theory led to **a Nobel Prize in Physics** for the three scientists in 1972.
- An important development in physics that elicited much excitement in the scientific community was the discovery of high-temperature copper oxide-based superconductors. The excitement began with a 1986 publication by J. Georg Bednorz (b. 1950) and K. Alex Müller (b. 1927), scientists at the IBM Zurich Research Laboratory in Switzerland. In their seminal paper,6 Bednorz and Müller reported strong evidence for superconductivity at 30 K in an oxide of barium, lanthanum, and copper. They were awarded the Nobel Prize in Physics in 1987 for their remarkable discovery.
- An important and useful application of superconductivity is in the development of superconducting magnets, in which the magnitudes of the magnetic field are approximately ten times greater than those produced by the best normal electromagnets. Such superconducting magnets are being considered as a means of storing energy. Superconducting magnets are currently used in medical magnetic resonance imaging, or MRI, units, which produce high-quality images of internal organs without the need for excessive exposure of patients to x-rays or other harmful radiation.
- A new family of compounds was found that was superconducting at "high" temperatures
  - Found materials that are superconductive up to temperatures of 150 K
- Although BCS theory was very successful in explaining superconductivity in metals, there is currently no widely accepted theory for high-temperature superconductivity. It remains an area of active research.
- The search for novel superconducting materials continues both for scientific reasons and because practical applications become more probable and widespread as the critical temperature is raised.
- If a room-temperature superconductor is ever identified, its effect on technology could be tremendous.

Text Books & References

1. **R.A. Serway and J.W. Jewett**, Physics for Scientist and Engineers with Modern Physics
2. **Halliday and Resnick**, Fundamental of Physics
3. **Hugh D.Young, Roger A. Freedman,** University Physics with Modern Physics, 13TH Edition
4. **Arthur Beiser, Concepts of** Modern Physics, Sixth Edition
5. **R Murugeshan and Kiruthiga Sivaprasath,** Modern Physics,


Thank you