

Solutions to the problems in Chapter 6

6.3 Pressure of a Fermi gas at zero temperature

The number of electrons N and the internal energy U , in the volume V , are

$$N = V \int_0^\infty D(\varepsilon) f(\varepsilon) d\varepsilon, \quad U = V \int_0^\infty \varepsilon D(\varepsilon) f(\varepsilon) d\varepsilon, \quad (1)$$

The Fermi distribution function $f(\varepsilon)$ and the density of states (per unit volume) $D(\varepsilon)$ are

$$f(\varepsilon) = \frac{1}{e^{\beta(\varepsilon - \mu)} + 1}, \quad D(\varepsilon) = A\sqrt{\varepsilon}, \quad A = \frac{\sqrt{2m^3}}{\pi^2 \hbar^3}. \quad (2)$$

At zero temperature

$$f(\varepsilon) = \theta(\varepsilon_F - \varepsilon), \quad \varepsilon_F = \frac{\hbar^2 k_F^2}{2m}, \quad k_F = (3\pi^2 n)^{1/3} \quad (3)$$

Introducing the step function and $D(\varepsilon) = A\sqrt{\varepsilon}$ in (1), we may determine $U(0)$ and an alternative expression for A :

$$N = V \int_0^{\varepsilon_F} A\sqrt{\varepsilon} d\varepsilon = \frac{2}{3} V A \varepsilon_F^{3/2} \Rightarrow A = \frac{3n}{2\varepsilon_F^{3/2}}, \quad U(0) = V \frac{2}{5} A \varepsilon_F^{5/2} = \frac{2}{5} N \varepsilon_F \quad (4)$$

i.e. $U \propto \varepsilon_F \propto k_F^2 \propto V^{-2/3}$ and the pressure at zero temperature is

$$P = -\frac{\partial U(0)}{\partial V} = \frac{2}{3} \frac{U}{V} = \frac{2}{3} n \varepsilon_F = \frac{(3\pi^2)^{2/3} n^{5/3} \hbar^2}{5m} \quad (5)$$

in sharp contrast to a classical gas, where the zero-temperature pressure is zero.

6.4 Density of states in low dimensions

The density of states in $\vec{k}$ -space is $D_{\vec{k}} = 2/(2\pi)^d$ in d dimensions (6.34)

$$D(\varepsilon) = \int |d\vec{k}| \delta(\varepsilon - \varepsilon_{\vec{k}}) \equiv \int D_{\vec{k}} \delta(\varepsilon - \varepsilon_{\vec{k}}) d\vec{k} = \frac{2}{(2\pi)^d} \int \delta(\varepsilon - \varepsilon_{\vec{k}}) d\vec{k} \quad (1)$$

Introducing "spherical coordinates" in d dimensions and $k = |\vec{k}|$, then

$$d\vec{k} = \begin{cases} 2 dk & , \quad d = 1 \\ 2\pi k dk & , \quad d = 2 \\ 4\pi k^2 dk & , \quad d = 3 \end{cases} \quad (2)$$

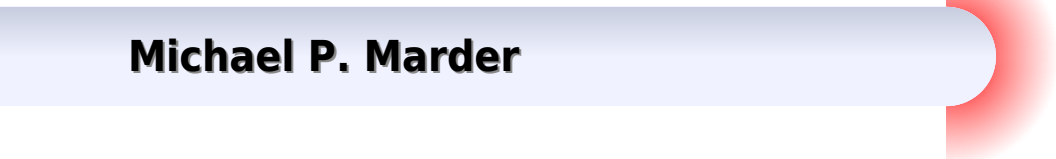
The factor 2 in the one-dimensional case appears because the one-dimensional wave vector may assume both positive and negative values, whereas $k \geq 0$ per definition.

$$\varepsilon_{\vec{k}} = \varepsilon_k = \frac{\hbar^2 k^2}{2m} \Rightarrow k = \frac{\sqrt{2m\varepsilon_k}}{\hbar}, \quad dk = \left(\frac{m}{2\hbar^2 \varepsilon_k} \right)^{1/2} d\varepsilon_k \Rightarrow \quad (3)$$

$$D(\varepsilon) = \begin{cases} \frac{2}{2\pi} \int_0^\infty 2 \delta(\varepsilon - \varepsilon_k) \left(\frac{m}{2\hbar^2 \varepsilon_k} \right)^{1/2} d\varepsilon_k = & \frac{\sqrt{2m}}{\pi \hbar} \varepsilon^{-1/2}, \quad d = 1 \\ \frac{2}{(2\pi)^2} \int_0^\infty 2\pi \frac{\sqrt{2m\varepsilon_k}}{\hbar} \delta(\varepsilon - \varepsilon_k) \left(\frac{m}{2\hbar^2 \varepsilon_k} \right)^{1/2} d\varepsilon_k = & \frac{m}{\pi \hbar^2}, \quad d = 2 \\ \frac{2}{(2\pi)^3} \int_0^\infty 4\pi \frac{2m\varepsilon_k}{\hbar^2} \delta(\varepsilon - \varepsilon_k) \left(\frac{m}{2\hbar^2 \varepsilon_k} \right)^{1/2} d\varepsilon_k = & \frac{\sqrt{2m^3}}{\pi^2 \hbar^3} \varepsilon^{1/2}, \quad d = 3 \end{cases}$$

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Solid-State Physics James D. Patterson, Bernard C. Bailey, 2019-02-20 This book teaches solid state physics in a comprehensive way covering all areas It begins with three broad topics how and why atoms bind together to form solids lattice vibrations and phonons and electrons in solids It then applies this knowledge to interactions especially those between electrons and phonons metals the Fermi surface and alloys semiconductors magnetism superconductivity dielectrics and ferroelectrics optical properties defects layered materials quantum Hall effect mesoscopics nanophysics and soft condensed matter Further important topics of the book are the evolution of BEC to BCS phenomena conducting polymers graphene iron pnictide superconductors light emitting diodes N V centers nanomagnetism negative index of refraction optical lattices phase transitions phononics photonics plasmonics quantum computing solar cells spin Hall effect and spintronics In this 3rd edition topics such as topological insulators quantum computing Bose Einstein transitions highly correlated electron systems and several others have been added New material on magnetism in solids as well as a discussion of semiconductors and a changed set of problems with solutions are also included The book also discusses folk theorems to remind readers of the essence of the physics without mathematics and includes 90 mini biographies of prominent solid state physicists of the past and present to put a human face on the subject An extensive solutions manual rounds out the book

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Qualifying Examination Horacio A. Farach, Charles P. Poole, Jr., John L. Safko, Sr., 2010-03-08 Designed for use in tandem with the Handbook of Physics this volume is nonetheless self contained and can be used on its own The chapters are based on lectures delivered annually by Professor Poole in a course to prepare students for their PhD qualifying examination in the physics department at the University of South Carolina The book contains 120 selected problems and answers that appeared in these examinations and each one refers to the chapter in the Handbook that discusses the background for it Professor Farach has kept a record of all the qualifying examinations in the department since 1981 It covers all relevant physics subjects which are otherwise scattered in different preparation publications or university scripts including Atomic and General Physics Condensed Matter Physics Classical Mechanics Electricity and Magnetism Elementary Particle Physics Nuclear Physics Optics and Light Quantum Mechanics Relativity and Astrophysics Thermo and Statistical Mechanics An excellent self study approach to prepare physics PhD candidates for their qualifying examinations Electronic Structure

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mathematical tools used to construct realistic models for a variety of different fields including condensed matter physics and quantum optics The various forms of the Bethe ansatz algebraic coordinate multicomponent and thermodynamic Bethe ansatz and Bethe ansatz for finite systems are then explained in depth and employed to find exact solutions for the physical properties of the integrable forms of strongly interacting quantum systems The Bethe ansatz is one of the very few methodologies which can calculate physical properties non perturbatively Arguably it is the only such method we have which is exact This means once the model has been set up no further approximations or assumptions are necessary and the relevant physical properties of the model can be computed exactly Furthermore an infinite set of conserved quantities can be obtained The quantum mechanical model under consideration is fully integrable This makes the search for quantum models which are amenable to an exact solution by the Bethe ansatz and which are quantum integrable so important and rewarding The exact solution will provide benchmarks for other models which do not admit an exact solution Bethe ansatz techniques provide valuable insight into the physics of strongly correlated quantum matter

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