Condensed Matter Physics 2023
Quiz 6 (Week 13)

1. A silicon (Si) crystal is doped with 10^{17} arsenic (As) atoms per cubic cm, $n_{\mathrm{As}} = 10^{17}$ cm^{-3}, at room temperature ($T = 300$ K). Other data that you will need: the band gap of Si is 1.1 eV, and the electron and hole effective masses are, respectively, 0.43 and 0.54 (in units of the free electron mass).
   (a) Does this doping make silicon N-type or P-type?
   (b) What is the free carrier concentration (for the majority carriers)?
   Note: we can assume that at this temperature the impurities are fully ionised.
   (c) Find the chemical potential (Fermi level) with respect to the bottom of the conduction band / top of the valence band (which one it is depends on your answers above). Does the result make sense?
   Note: be careful with the units (of course you can give the result either in eV or J).
   (d) What would be the chemical potential at the same temperature for intrinsic (undoped) silicon instead?

2. Given the magnetic susceptibilities below, indicate which of these materials is ferromagnetic, paramagnetic and diamagnetic and why.
   (a) 1×10^{-4}
   (b) 2×10^{5}
   (c) -3×10^{-5}

3. Calculate the molar susceptibility for a He atom, assuming an average electron radius of 0.58 Å.
   Note: for the molar susceptibility you need to consider the number of electrons in a mole of He.

4. An atom with a magnetic dipole moment $\mu = 2\mu_B$ is subject to a magnetic field $H = 10^6$ A/m. If the moment rotates from antiparallel to the field to parallel to the field, by how much does the energy of the atom change? At $T = 300$ K, what fraction of $k_B T$ is this energy? Could this change in orientation of the magnetic moment be thermally driven?
   Note: you can consider $B = \mu_0 H$; and $\mu_B = e\hbar/(2m) = 9.274 \times 10^{-24}$ J/T.