**Answers to Chapter Sample Problems**

**Chapter 1**

* 1. For Ti2+, the electron configuration is 3d2, so *S* = 1, *L* = 3, therefore *J* = 2, *gJ* = 2/3 and *pJ* = 1.63, *pS* = 2.82. The experimental value *p*exp is 2.8, very close to the spin-only moment, indicating that when Ti2+ is chemically bonded, the orbital moment is quenched by the crystal field of the neighbouring ions, as the 3d electrons are no longer shielded by the 4s electrons normally present in the outermost shell.
	2. For V2+ or Mn4+, the electron configuration is 3d3, so *S* = 3/2, *L* = 3, therefore *J* = 3/2, *gJ* = 0.4 and *pJ* = 0.77, *pS* = 3.87. The experimental value *p*exp is 3.8, showing again that the orbital moment is quenched. However, it is not exactly zero and in this case (a half-filled shell) it acts against the spin-only contribution to reduce the overall moment.
	3. Assuming the high-spin configuration, for Mn3+ the electron configuration is 3d4, so *S* = 2, *L* = 2, therefore *J* = 0, *pJ* = 0 and *pS* = 4.92. The experimental moment is *p*exp = 4.9, almost exactly the spin-only moment. It seems counterintuitive that the total angular momentum is zero but the measured moment is large; the apparent contradiction is explained by the fact that Hund’s rules strictly apply to the ground state, where S and L in Mn3+ compensate each other. However, due to a very close energy level spacing relative to *kBT* in Mn3+, thermal excitations allow the d-electrons to populate the first excited state *ψ*e (for which *J*=1) from the *J*=0 ground state *ψ*0. In spectroscopic notation, the ground state configuration t32ge1g is altered by the promotion of one electron to give a new configuration t22ge2g.
	4. By substituting the values for *a0* = 0.529 Å, *e* = 1.609 x 10-19 C, *me* = 9.109 x 10-31 kg, µ0 and *NA*, the molar Larmor susceptibility for graphite is evaluated to be -6.0187 x 10-11 m3/mol in SI units. From the Magnetic Units conversion table, the SI molar susceptibility should be divided by the factor 4π x 10-6 to obtain the CGS molar susceptibility, giving -4.7895 x 10-6 cm3/mol. The experimental value (which includes all contributions) from Table 1.4 is -6.0 x 10­-6 cm3/mol, so the agreement is quite good.
	5. Repeating the exercise for Cu gives a value for the Larmor molar susceptibility of -23.149 x 10­-6 cm3/mol. This is in rather poor agreement with the experimental value of -5.46 x 10­-6 cm3/mol.
	6. Using the suggested substitution and Equation 1.10, the SI expression for the molar Larmor susceptibility in a metal becomes $χ\_{Larmor}^{molar}= -N\_{A}\frac{e^{2}μ\_{0}}{6m}\left(\frac{3A}{4πN\_{A}Z\_{i}ρ\_{m}}\right)^{\frac{2}{3}}$. Using the values *Zi* = 1, A = 63.546 g/mol, *ρm* = 8933 kg/m3, the SI value of the susceptibility is evaluated as -7.155 x 10-11 m3/mol, giving a CGS value of -5.69 x 10-6 cm3/mol. This is in much better agreement with the experimental value of -5.46 x 10-6 cm3/mol from Table 1.4, showing that the delocalised nature of the electrons in metals requires a different way of estimating the radius of the outermost electron shell.

**Chapter 2**

1. Yes.
2. Yes, it does. For a specific application not all the synthesis routes can be used.
3. Versatility will come first.

**Chapter 3**

1. From the density, diameter and concentration information given it is possible to calculate the number of nanoparticles in our 100 μl sample, this is x. Applying Beer’s law to the absorbance reading (l = 1 cm) gives the concentration of amines in our 5 ml sample as y. This gives a loading level of 50\*y/x = z
2. There are several possible routes, the key is to eliminate possible side reactions, to see how this problem was solved – see ref [21].

**Chapter 4**

* Optical tweezers
* Magnetic tweezers
* Electric tweezers
* Optoelectronic tweezers
* Catalytic tweezers
* Acoustic tweezers
* Plasmon nano-optical tweezers
* Optical tweezers: mostly dielectric and relatively large particles (micron scale).
* Magnetic tweezers: only magnetic particles
* Electric tweezers: no limitations on materials and geometries
* Optoelectronic tweezers: no limitations on materials and geometries
* Catalytic tweezers: asymmetric chemical composition (e.g., bimetal nanorods or Janus microbeads)
* Acoustic tweezers: relatively low precision and mostly useful for micron scale objects
* Plasmon nano-optical tweezers: effective for nanoparticle trapping
* Drug and micro/nanoscale cargo delivery.
* Trapping and sorting biochemical molecules.
* Measurement of the mechanical properties of biological molecules and structures.
* Measurement of electric properties of nanoentities and the surrounding media.
* Robotized biomedical sensing.
* Particle size and magnet size
* Localized magnetic fields
* Size of vascular system at target site
* Oxidative state of the magnetic material
* Degradation products and other released molecules including solvents or materials used during MDC/particle synthesis
* Accumulation of these products/materials over time in susceptible tissues
* Magnetic Resonance Imaging (diagnostic)
* Magnetic hyperthermia (therapeutic)

**Chapter 5**

1. Pulsatile blood flow in larger blood vessels

2. Twisting blood flow

3. Uneven wall geometry

4. Blood cells and particulates found in blood flow

5. Newtonian rheology is assumed in the model

6. It is assumed that the nanoparticles are exactly the same size and composition

1. Figure 5.8A (in this book chapter) represents nanoparticle capture at a low flow rate - In this regime, all the nanoparticles either arrive at the wall with a capture angle less than the critical capture angle, but then "roll" along the wall until they become immobilized or they arrive at the wall with a capture angle greater than the critical capture angle and are immediately immobilized. The most upstream point of nanoparticle capture will correspond to where the critical capture angle has just been achieved and the most downstream point of capture will vary according to the relative magnitude of the fluid flow and the externally applied magnetic flux.

Figure 5.8B (in this book chapter) represents nanoparticle capture at a high flow rate - Some of the particles that do contact the wall will either "roll" along the wall until they are immobilized or they will be immobilized immediately. There will be a dividing particle trajectory that will result in a particle arriving at the wall at exactly the critical capture angle. Any particles that arrive at the capillary wall downstream of this position will continue with the fluid flow and any particles that arrive at the capillary wall upstream of this position will be immobilized.

**Chapter 6**

1. The first step is to estimate the charge carrier concentration (*N*) and since silver has an electron configuration of [Kr] 4d10 5s1 that leaves one single free conduction electron. Hence, this can be calculated based upon the density of silver:

$$N=\frac{N\_{A}}{M}ρ=\frac{6.02×10^{23}mol^{-1}×10.49g.cm^{-3}}{107.87g.mol^{-1}}=5.85×10^{22} cm^{-3}$$

Where,

$N\_{A}=6.02×10^{23} mol^{-1}$ is Avogadros constant.

$ρ=10.49 g.cm^{-3}$ is the density of silver at room temperature.

$M=107.87 g.mol^{-1}$ is the atomic mass of silver.

In order to derive an estimate for the drift velocity one must use the SI convention of current defined as the charge transfer of $6.24×10^{18}$ electrons per second or more commonly known as the Ampere. Adopting these values to a practical application such as supplying 10A of current to power a kettle or toaster, the drift velocity of the electrons can be calculated:

$$v=\frac{I}{eNA}=\frac{10A}{1.60×10^{-19}C×5.85×10^{22}cm^{-3}×0.01cm^{2}}=0.107 cm.s^{-1} $$

Where,

$I=10A$ is the current required to power a kettle or toaster.

$e=1.60×10^{-19}C$ is the charge of an electron ($^{1}/\_{e}=6.24×10^{18}C^{-1})$

$N=5.85×10^{22}cm^{-3}$ is the charge carrier concentration as estimated above.

$A=1 mm^{2} or 0.01 cm^{2}$ is the cross sectional area of standard household electrical wire.

As expected the drift velocity is larger for silver than for copper as the former is the better conductor.

1. Field at the sensor surface is B ~4 μT, and the average is B= 1 nT.
2. A *magnetic biosensor* is a compact analytical device incorporating a biological, a biologically derived material associated with a physicochemical magnetic transducer or transducing microsystem [4].
3. The ***magnetoimpedance*** phenomenon consists in the change of the total impedance of a ferromagnetic conductor, *Z*, under application of an external magnetic field when a high frequency alternating current, *I = I0 e2πift*, flows through it.
4. Two of the most important characteristics of the magnetic field detector are the sensitivity with respect to external magnetic fields, *i.e.* signal per unit field and magnetic field resolution*, i.e.* smallest field which will trigger a response from the sensor.

**Chapter 7**

1. Heat-up method represents a synthetic method for nanoparticles where reactants are heated up in an organic solvent to form inorganic nanocrystals. Heat-up method yields monodisperse nanocrystals with high crystallinity. Thus, their magnetic property, which is critical to MRI contrast effect, is superior compared with a nanoparticles synthesized via a coprecipitation method. In addition, the size of nanoparticles can be tuned by varying reaction conditions such as temperature, concentration of reaction, and ratio of precursors and surfactants. Because the magnetic property is dependent on the size of nanoparticles, heat-up method allows synthesis of paramagnetic (< 3 nm), suparamagnetic (3 ~ 20 nm), and ferromagnetic (> 20 nm) iron oxide nanoparticles. In addition, size of nanoparticles affects cellular uptake, biodistribution, and pharmacokinetics, which are very critical for clinical applications. Heat-up method allows reproducible control of these factors by changing the size of nanoparticles.
2. Owing to lower magnetization, *T*2 contrast effect of superparamagnetic nanoparticles is lower than that of ferrimagnetic nanoparticles. However, the contrast effect of superparamagnetic nanoparticles can be improved by clustring of nanoparticles and control of coating thickness. In addition, high colloidal stability of superparamagnetic nanoparticles allows easy modification, facilitating development of multifunctional nanomaterials. At last but least, FIONs cannot be directly injected into blood vessels because their permanent magnetization induces aggregation even in the absence of magnetic field. Thus, FIONs can be used in a limited applications such as MR tracking of transplanted cells. On the contrary, superparamagnetic nanoparticles can be used in various clinical situations including cancer diagnosis, monitoring of atherosclerosis, delivery of cargoes, and blood pool imaging.
3. In general, strong *T*2 contrast effect sacrifices *T*1 contrast effects. Consequently, it is very difficult to observe *T*1 contrast effect of Feridex even though its *r*1 value is much higher than that of Gd-complexes (Table 7.1). While *T*2 contrast effect depends on the magnetic field strength generated by nanoparticles, *T*1 contrast effect is dependent on the accessiblity of water molecules to paramagnetic ions. Thus, if magnetic cores and paramagnetic ions are separated by a suitable distance, *T*2 material cannot perturb *T*1 relaxation process. Recently, it is reported that MnFe2O4@SiO2@Gd2O(CO3)2 core/shell nanostructure can be used as dual mode contrast agents (*J. Am. Chem. Soc.* **132 (**2010), 11015-7.).

**Chapter 8**

1. Magnetotactic bacteria are a phylogenetically, morphologically and physiologically diverse group of prokaryotes that biomineralize intracellular magnetic crystals of the minerals magnetite (Fe3O4) or griegite (Fe3S4) called magnetosomes that cause them to align and swim along magnetic field lines like miniature, motile compass needles.
2. While we probably do not know how magnetosomes function in every detail, for example, it is not known whether there is a cellular physiological function perhaps in electron transport, it is current thought that magnetosomes aid the cell in making chemotaxis (e.g., aerotaxis) more efficient by reducing a 3-dimensional search problem to one of a single dimension in locating an optimal position for survival and growth in vertical chemical gradients typical of natural habitats.
3. Over the last decade or so, a relatively large number of genes and proteins have been found to be involved in magnetosome synthesis (including the size and shape of the individual crystals) and arrangement within the cell. Although the specific roles of each gene/protein have not been completely elucidated, there is now no question that magnetotactic bacteria cannot biomineralize magnetosomes without a specific subset of these gene/proteins.