

PHY138Y –Supplementary Notes Summaries

These notes are intended as a study guide for the Supplementary Notes. In each section I've listed the important information that I hope you will know and understand.

Historical Notes: this lists the scientists whose contribution I expect you to be able to identify.

Comprehension: this section names the most important ideas that you should be able to understand and explain, if asked.

Memorization and definitions: there are some definitions of quantities and a few salient facts that have not been derived from simple principles; the ones I'd expect you to remember are listed in this section.

**As I've emphasized in class, if you can't quote – in words –
the definition of a quantity, you'll never be able to understand its use.**

Formulae: here is listed the main formulae you will need; these could help you make up the formulae list that you will prepare for your '*Cheat Sheet*' for the test and exam. You should not need to memorize the formulae. However, unless otherwise stated, you should assume that I might ask you to derive them from first principles, knowing the definition of the quantities involved.

I've tried to include all of the things that you will need to do well in the test and exam – but *caveat emptor!* Remember, none of the material in the Appendices to the Supplementary Notes is examinable. If you find these summaries useful, please check them carefully and let me know if I've missed anything.

Summary of SNI

Historical Notes. The main contribution of each of the following: Boltzmann, Thomson, Rutherford, Becquerel, Bohr, Einstein (the photon, $E=mc^2$).

Comprehension.

Discovery of the Nucleus (Rutherford's experiment, the Plum Pudding and the Planetary Model)

The Origin of Line Spectra (Bohr model of the atom)

Energy – Mass Equivalence

Binding energy ; Ionization energy

E-M waves and the E-M spectrum; the Photon

Memorization and definitions.

Properties of the Nucleus (A, Z, N)

Approximate atomic and nuclear size

Binding Energy, Isotopes, Radioisotopes

eV, amu, Mole, Avogadro's Number

Formulae.

$$E = mc^2, E = hf, \lambda f = c, E_\gamma = hf = E_i - E_f$$

Summary of SNII

Historical Notes. Discovery of X-rays (Roentgen), Hounsfield (CT scans)

Comprehension.

X-ray machines – how they work

Bremsstrahlung Radiation and Wavelength cutoff

Characteristic X-rays and atomic levels

Interaction of X-rays with matter: Photoelectric effect, Compton Effect, Pair Production

Exponential decrease in intensity with depth in matter

Formulae.

$$\lambda_{min} = c/f_{max} = hc/E_{max}^e ; d\Phi = -\mu\Phi dx, \Phi(x) = \Phi(0) \exp(-\sum \mu_i x_i)$$

Memorization and definitions.

Typical X-ray energy ranges for therapy and diagnosis

Approx. fraction of electron energy given up as X-rays

Approx. Range of X-ray energies for each of PE effect, Compton Effect, Pair Production

X-rays more penetrating than similar energy electrons

μ increases with density, decreases with energy

μ/ρ approx. constant at high energies

Definitions and units : exposure (R), absorbed dose (Gy, rad), photon fluence and fluence rate, energy fluence and fluence rate, linear attenuation coefficient, mass attenuation coefficient

Summary of SNIII

Historical Notes. Becquerel, Rutherford, Marie and Pierre Curie, Pauli

Comprehension.

Parents and daughters; the radioactive decay law, number of nuclei, activity

Types of decay: α decay – what it is; why KE of alpha \gg KE of daughter
 (NB – you don't need to understand classical impossibility of the decay)
 β decay – why β has a spectrum of kinetic energies;
 – why neutrino hypothesis was necessary
 γ decay – understanding its source in excited nuclei
 Electron capture – what it is

Energetics and the Q value, or disintegration energy; how much of Q is carried off by the daughters of each decay. Difference between listed atomic masses and nuclear masses

Formulae.

$Q = (\text{nuclear mass of parent} - \text{sum of nuclear mass of decay products}) \cdot c^2$

$dN(t) = -\lambda N(t) dt$; $N(t) = N(0) \exp(-\lambda t)$; $T_{1/2} = \ln_e 2 / \lambda$;

$R(t) = |dN/dt| = R(0) \exp(-\lambda t) = \lambda N(t)$.

Memorization and definitions.

Decay Law, Activity, decay constant, half-life

Mass of neutrino is zero. Isomeric state

Summary of SNIV

Historical Notes. Rolf Sievert

Comprehension.

Relation between exposure, absorbed dose, and energy fluence

Energy absorption coefficient, mass energy absorption coefficient

Exponential deposition of energy in matter

Necessity for weighting factors W_R , W_T ; equivalent and effective dose

Formulae.

$$Sd\Psi = -\Delta E = -\mu_{en}\Psi(x) S dx; \Psi(x) = \Psi(0) \exp(-\mu_{en}x); D_m(x) = (\Delta E/m) = (\mu_{en}/\rho)_m \Psi(x)$$

$$H = W_R \cdot D_m; H_{eff} = \sum W_T H_T$$

Memorization and definitions.

Energy fluence, energy absorption coefficient, mass energy absorption coefficient

$(\mu_{en}/\rho)_m$ approx. constant at high energies

Radiation weighting factors (W_R , RBE or Quality Factor, Q or QF), equivalent dose

$W_R = 1$ for X-rays, electrons. $\sum W_T = 1$ for whole body exposure

Tissue weighting factor (W_T), effective dose (H_{eff}) = $\sum W_T H_T$

Definition of Sievert

Background Radiation: about 3 mSv/year (N.America), with wide variation;

80% natural (65% radon, 20% soil/rocks, 15% body), 20% man-made (80% medical)

CNSC limits – 50 mSv in one year, 100mSv over five years

Meaning of Deterministic, Stochastic risk;

High dose above about 1 Sv, death above 4 or 5 Sv

Meaning of carcinogenesis, mutagenesis

The LNT hypothesis.

Benefit of photon over electron radiation in therapy

Fractionation, rotation therapy

Summary of SNV

Historical Notes.

Comprehension.

Radioisotopes as tracers (diagnosis); tracers – SPECT, PET

Isotopic Dilution, meaning of exchangeable pool

Radioisotopes for therapy – Teletherapy, Brachytherapy

Radiometry - Committed Dose.

Biological Excretion; nuclear, biological, and effective decay constants λ_n and λ_{be} and λ_{eff}

Understanding of the Generation of Radioisotopes and the use of Milking

Formulae.

$$V = v R / r ;$$

There are many formulae in 5.4.2. All can be easily reduced to the most general ones quoted here – e.g. the case in which there is no biological excretion is recovered by replacing λ_{eff} in these formula by λ ($=\lambda_n$); the committed dose to infinite time is obtained by letting $T \rightarrow \infty$ in $D_m(0 \rightarrow T)$. You should be able to derive the expression for committed dose from first principles.

$$\dot{D}_m(0) = e_n R(0) / m ; \text{ (this is obvious from the definitions of the quantities)}$$

These next, also obvious from the definitions, are easily remembered, and

$$dN_n(t) = -\lambda_n N(t) dt ; dN_{be}(t) = -\lambda_{be} N(t) dt ; \lambda_{eff} = \lambda_n + \lambda_{be} ;$$

$$dN(t) = dN_n(t) + dN_{be}(t) ; dN_n(t)/dN(t) = \lambda_n/\lambda_{eff}$$

$$dN(t) = -\lambda_{eff} N(t) dt ; N(t) = N(0) \exp(-\lambda_{eff} t) ; R(t) = R(0) \exp(-\lambda_{eff} t) \text{ [in the organ];}$$

This general one is useful - easily adapted to particular cases; e.g. $\lambda \rightarrow \lambda_n$ or $T \rightarrow \infty$

$$D_m(0 \rightarrow T) = \dot{D}_m(0) \{1 - \exp(-\lambda_{eff} T)\} / \lambda_{eff}$$

You are not expected to derive or memorize the formulae for the parent or daughter decay here:

$$\begin{aligned} dN_2(t)/dt &= \lambda_1 N_1(t) - \lambda_2 N_2(t) ; \\ R_2(t) &= \lambda_2 N_2 = \lambda_1 N_1 \{ \lambda_2 / (\lambda_2 - \lambda_1) \} \{ 1 - \exp[-(\lambda_2 - \lambda_1)t] \} \\ &= R_1(t) \{ \lambda_2 / (\lambda_2 - \lambda_1) \} \{ 1 - \exp[-(\lambda_2 - \lambda_1)t] \} \end{aligned}$$

Memorization and definitions.

Use of Tracers – Technetium (^{99m}Tc) is a common one; ^{18}F for PET

Teletherapy (^{60}Co bomb), Brachytherapy (incl. catheter use)

Committed dose, biological excretion and decay constant, effective decay constant

AECL radioisotopes, use of milking ($^{99}\text{Mo} \rightarrow ^{99m}\text{Tc}$)

Summary of SNVI

Historical Notes. Contributions of Uhlenbeck, Pauli, and Goudsmit (fine splitting), Paul Lauterbur, Peter Mansfield, Raymond Damadian.

Comprehension.

Spin ‘spin $\frac{1}{2}$ particles’; quantization. The Larmor Frequency, magnetization.

Energy difference between “up” and “down” states of the proton.

Faraday’s law (qualitative)

Meaning of resonant condition.

Measurement of Larmor frequency - application of a rf pulse, meaning of 90° pulse.

Use of the gradient field to provide slice position, and generalization to voxels

Relaxation times and their diagnostic value.

Memorization and definitions.

Definition of the Larmor frequency.

Gyromagnetic ratio γ – the ratio between the magnetic moment, μ , and the z component of the spin of the proton.

Formulae.

$\nu_L = \omega_L/2\pi$; $\omega_L = \gamma B_0$, $s_z = \frac{1}{2} \hbar$. $\nu_L \approx 42 B_0$ (with B_0 in T, ν_L in MHz).

The number of particles occupying a state of energy E is proportional to $\exp(-E/kT)$

$\Delta E = 2\mu B_0$; $n_+/n_- \approx \exp(\Delta E/kT)$; $\Delta E = h\nu_L = (h/2\pi) \omega_L = \hbar\gamma B_0 = 2\mu B_0$.

$\omega_L(z) = \gamma B_z = \gamma (B_0 + zG_z)$; $\Delta z = \Delta\omega / (\gamma G_z)$;

$M_z = |M| [1 - \exp(-t/T_1)]$; $M_{xy} = |M| \exp(-t/T_2)$.