You are encouraged to attempt past examination papers to prepare for this year's examination. Numerical values, hints and similar information are given below so that you can check your attempts. Note that there is not necessarily only one correct way to approach questions, and where estimates are required, a range of values may be acceptable, especially if justified by reasonable arguments. If you have attempted past questions and wish to discuss the details of your calculations, please see me!

Dr Booth

Question 1

Consider the relationship between changes in kinetic energy, potential energy and work done against air resistance, for both the ascent and descent. Hence show that time taken to ascend to highest point must be less than time taken to descend. (Alternatively, consider forces rather than energy.)

Question 2

Consider the capacitor as lots of thin strips, in parallel. Each strip effectively consists of two capacitors in series, one with and one without dielectric. Integrate across the plates to get the total capacitance of 4.21 pF.

Question 3

Write down the force between the 4 (external) pairs of charges. Expand using the binomial expansion for $d \ll a$, keeping the first non-zero term. Hence $F = \dfrac{3p_1p_2}{2\pi\varepsilon_0 a^4}$, repulsive.

Question 4

Determine the dimensions for magnetic dipole moment μ and magnetic field B (e.g. from $\mu = Ia$ and $F = q\mathbf{v}\times\mathbf{B}$) in terms of M, L, T and either Q or I. (Be careful not to confuse I for current and I_0 for moment of inertia!) Hence $f \propto \sqrt{\dfrac{\mu B}{I_0}}$.

Question 5

The momentum is $\gg mc$, so relativistic expressions are essential. Using $p = \gamma m v$ to find v for each particle gives a time difference of 1.5 ns, easily resolvable. The general expression for p in terms of Δt is complicated, but a binomial expansion in $(mc/p)^2$ gives a simple expression which is quite accurate. Hence $p_{\text{max}} = 5.36\ \text{GeV}/c$.

Question 6

Only the periods, masses etc given in the question should be used! The radius of the earth and radius of the moon's orbit are eliminated using g and G. (It might have been better if the question had given the mass of the moon as about 1/80$^{\text{th}}$ that of the earth! Instead an estimate had to be made.) The ratio of angular momenta is thus about 4.0:1.

Question 7

Use Kirchhoff's rules and solve the simultaneous linear equations to determine that $R^* = \dfrac{2R}{5}$.

Question 8

Equate the gravitational and electrostatic forces at equilibrium, and hence find the contributions to potential energy.

Question 9

Label the angles of incidence and reflection at the air-glass interface and the critical angle at the glass-water interface. Using Snell's law for the former and simple geometry, show that the angle of reflection is ϕ (as defined in the question) to derive the stated result.

Question 10

Use $\mathrm{d}S = \frac{\mathrm{d}Q}{T}$ to obtain the given expression. Put in values to obtain $\frac{\Omega_\mathrm{f}}{\Omega_\mathrm{i}} = 10^{8.6\times10^{23}}$.

Question 11

Sketch the decay chain for the case of maximum neutrino energy. Use conservation of energy and momentum in the Z decay to find E_Z in terms of E_ν, hence minimum neutralino mass is 210 GeV/c^2.

Question 12

Again, a diagram helps! Equate loss in gravitational PE to PE in elastic at maximum extension to derive $l_0 = \sqrt{h(h-2h')}$. Maximum speed occurs on passing through equilibrium position, hence $v_{\max}^2 = g\left(h - h' + l_0\right)$. (Other expressions are possible.)

Question 13

From diffraction data, pitch is 740 nm. Estimate useful area of DVD from dimensions, hence length of spiral is 14 km. Therefore size of single bit is 370 nm.

Question 14

About 2/3 of the earth's surface is ocean and 1/3 land, so on average 5/6 m evaporates per year. Multiply by the surface area of the earth to get the volume, and the density to get the mass of rain per year. Assume this falls on land with an average useful river descent of ~1000 m to find the lost potential energy which could be converted to hydroelectric power. Hence maximum power is about 1.4×10^{14} W.

Question 15

There are various approaches, e.g. using the commutator [*A*,*B*] to swap each occurrence of *BA* to *AB* obtains the required results.