**Q11** [*Uncertainty principle*] The statements in the key are related to wave packets and the uncertainty principle. Select from the key the two *correct* statements, and pencil across *two* cells in row 11.

KEY for Q11

A A wave packet can only be used to describe a particle if the particle's momentum is known exactly.

B The more localized a wave packet is, the larger is the range of wavelengths from which it is constructed.

C If the position of the $x$-component of a particle has an uncertainly $\Delta x = 10^{-9}$ m, the $x$-component of its momentum can, in principle, simultaneously be known to a precision of $10^{-26}$ kg m s$^{-1}$.

D A non–zero uncertainty $\Delta y$ in the $y$-component of the position of an electron in the ground state of a hydrogen atom means that there is a limit to which its total energy can be simultaneously known.

E If the energy of a particle is measured at a time that is known with an uncertainty of $10^{-10}$ s, then the uncertainty in the measured energy cannot be greater than $10^{-24}$ J.

F An uncertainty $\Delta p_x$ in the $x$-component of a particle's momentum places no restriction on the limits to which $p_y$ and $p_z$, the $y$- and $z$-components of its momentum are known.

**Q12** [*Three-dimensional infinite well*] An electron is confined inside a cubic container with impenetrable walls, each of whose sides has length $D$. The potential energy of the confined electron is always zero, and, according to quantum mechanics, its energy levels are given by

$$E_{n\alpha} = \frac{h^2}{8m_e D^2}(n_1^2 + n_2^2 + n_3^2)$$

where $n_1 = 1, 2, 3, \ldots$, $n_2 = 1, 2, 3, \ldots$, $n_3 = 1, 2, 3, \ldots$.

When the electron makes a transition from its third lowest energy level to its lowest energy level, a photon of electromagnetic radiation is emitted. What is the frequency associated with this photon? Choose the *one* correct statement from the key, and pencil across *one* cell in row 12.

KEY for Q12

A $\frac{3h^2}{4m_e D^2}$

B $\frac{9h}{8m_e D^2}$

C $\frac{8m_e D^2}{3h}$

D $\frac{3h}{4m_e D^2}$

E $\frac{4m_e D^2}{3h}$

F $\frac{3h}{8m_e D^2}$

G $\frac{9h^2}{8m_e D^2}$

H $\frac{3h^2}{8m_e D^2}$

## PART D

*The questions in this part relate to Unit 15.*

**Q13** [*Schrödinger's theory*] The key contains seven statements about the Schrödinger equation, and its application to the hydrogen atom. Which *two* statements are wrong? Pencil across *two* cells in row 13.

KEY for Q13

A Quantum mechanics could, in principle, be used to study the motion of a satellite orbiting around the Moon.

B A particle confined to an infinite one-dimensional square well, can, according to Schrödinger's equation, occupy any one of an infinite number of energy levels.

C It is possible for a particle bound in this vicinity of a potential well of finite height and depth to be detected outside the well, even though its total energy is less than the potential energy at the top of the well.

D One of the triumphs of Schrödinger's equation is that it predicts that *four* quantum numbers, $n$, $l$, $m_l$ and $m_s$ are needed to specify each quantum state of an electron in a hydrogen atom.

E In general, the higher energy levels of an electron in a hydrogen atom are more closely spaced in energy than the lower energy levels.

F According to the Schrödinger theory, the 4f state of a hydrogen atom is split into 7 different energy levels in the presence of an external magnetic field. (You may ignore the effects of electron spin.)

G In a hydrogen atom, the principal quantum number, $n$, determines the value of the electron's energy levels under all circumstances.

**Q14** [*Heavy atoms*] Titanium has an atomic number of $Z = 22$, and one of its isotopes has a mass number $A = 60$. Which *two* statements in the key are correct? Pencil across *two* cells in row 14.

KEY for Q14

A All isotopes of titanium contain 38 protons.

B Titanium is in the same period of the Periodic Table as cobalt, Co.

C The three outer shells of titanium have structure $3p^6\,4s^2\,3d^2$.

D A titanium atom in its ground state does not have an electron in a state with $n > 3$.

E The electron energy levels in titanium are identical to those of all other atoms with $A = 60$.

F The positive charge on the nucleus of the titanium isotope that has mass number $A = 60$ is smaller by $6.4 \times 10^{-19}$ C than that on the isotope $^{56}_{22}$Ti.

G A titanium atom in its ground state has at least one electron with an orbital angular momentum quantum number equal to 3.