Q9 An electron in an atom remains in a certain excited state for a time of 5×10^{-10} s before returning to the ground state. To what precision, approximately, can the energy of the excited state be specified?

3p

Q11 Determine the minimum possible total energy of a gas of seven identical fermions if the energies of the twelve lowest-energy quantum states (allowing for spin) are as shown in Figure 5. ~~Select *one* option from the key and pencil across *one* row in Q11.~~

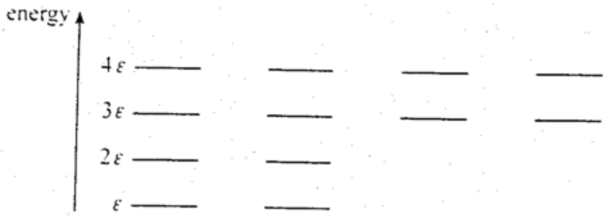

Figure 5 For use with Q11.

3p

Q10 What is the maximum number of electrons that can occupy the 3d subshell of an atom?

3p

Useful constants

magnitude of the acceleration due to gravity (on Earth)	g	$= 9.81\ \mathrm{m\,s^{-2}}$
Newton's universal gravitational constant	G	$= 6.673 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}$
Avogadro's constant	N_m	$= 6.022 \times 10^{23}\ \mathrm{mol^{-1}}$
Boltzmann's constant	k	$= 1.381 \times 10^{-23}\ \mathrm{J\,K^{-1}}$
molar gas constant	R	$= 8.314\ \mathrm{J\,K^{-1}\,mol^{-1}}$
permittivity of free space	ε_0	$= 8.854 \times 10^{-12}\ \mathrm{C^2\,N^{-1}\,m^{-2}}$
	$1/4\pi\varepsilon_0$	$= 8.988 \times 10^{9}\ \mathrm{N\,m^2\,C^{-2}}$
permeability of free space	μ_0	$= 4\pi \times 10^{-7}\ \mathrm{T\,m\,A^{-1}}$
speed of light in vacuum	c	$= 2.998 \times 10^{8}\ \mathrm{m\,s^{-1}}$
Planck's constant	h	$= 6.626 \times 10^{-34}\ \mathrm{J\,s}$
	$\hbar = h/2\pi$	$= 1.055 \times 10^{-34}\ \mathrm{J\,s}$
Rydberg constant	R	$= 1.097 \times 10^{7}\ \mathrm{m^{-1}}$
Bohr radius	a_0	$= 5.292 \times 10^{-11}\ \mathrm{m}$
atomic mass unit	amu (or u)	$= 1.6605 \times 10^{-27}\ \mathrm{kg}$
charge of proton	e	$= 1.602 \times 10^{-19}\ \mathrm{C}$
charge of electron	$-e$	$= -1.602 \times 10^{-19}\ \mathrm{C}$
electron rest mass	m_e	$= 9.109 \times 10^{-31}\ \mathrm{kg}$
charge to mass ratio of the electron	$-e/m_e$	$= -1.759 \times 10^{11}\ \mathrm{C\,kg^{-1}}$
proton rest mass	m_p	$= 1.673 \times 10^{-27}\ \mathrm{kg}$
neutron rest mass	m_n	$= 1.675 \times 10^{-27}\ \mathrm{kg}$
radius of the Earth		$6.378 \times 10^{6}\ \mathrm{m}$
mass of the Earth		$5.977 \times 10^{24}\ \mathrm{kg}$
mass of the Moon		$7.35 \times 10^{22}\ \mathrm{kg}$
mass of the Sun		$1.99 \times 10^{30}\ \mathrm{kg}$
average radius of Earth orbit		$1.50 \times 10^{11}\ \mathrm{m}$
average radius of Moon orbit		$3.84 \times 10^{8}\ \mathrm{m}$

Question 18 State how the *Born interpretation* relates the probability of finding a particle which is confined to the x-axis to its normalized wavefunction $\psi(x)$. *(2 marks)*

Question 26 The following results can be deduced from Planck's radiation law:

The total number of photons in a cavity in thermal equilibrium at temperature T is given by

$$N = 2.4C(kT)^3$$

where C is a constant and k is Boltzmann's constant.

The total energy of the photon gas is

$$U = \frac{\pi^4 C(kT)^4}{15}.$$

(a) Show that the average energy of a single photon at the temperature $T = 1.00\,\mathrm{K}$ is given by

$$\langle E \rangle = 3.73 \times 10^{-23}\,\mathrm{J}.$$

(2 marks)

(b) Determine the electromagnetic wavelength λ that this average photon energy corresponds to. *(3 marks)*

(c) The total number of photons in a cavity of volume $1.00\,\mathrm{m}^3$ at a temperature of $1.00\,\mathrm{K}$ is given by 2.03×10^{7}. Estimate the typical distance d between the photons at temperature $T = 1.00\,\mathrm{K}$. (You may use a model where photons are imagined to occupy the points in a cubic lattice.) *(2 marks)*

(d) Show that

$$d/\lambda \approx 0.7.$$

What does the value of this ratio tell you about the nature of the photon gas in the cavity? *(3 marks)*

[END OF QUESTION PAPER]

Question 25 *(a)* Compare the predictions of the Bohr model of the ground state of the hydrogen atom with the predictions of the Schrödinger model, with regard to:

(i) the distance of the electron from the nucleus;

(ii) the magnitude of the orbital angular momentum of the electron;

(iii) the total energy of the electron.

(5 marks)

(b) Figure 7 shows some energy levels of the helium atom alongside some of hydrogen.

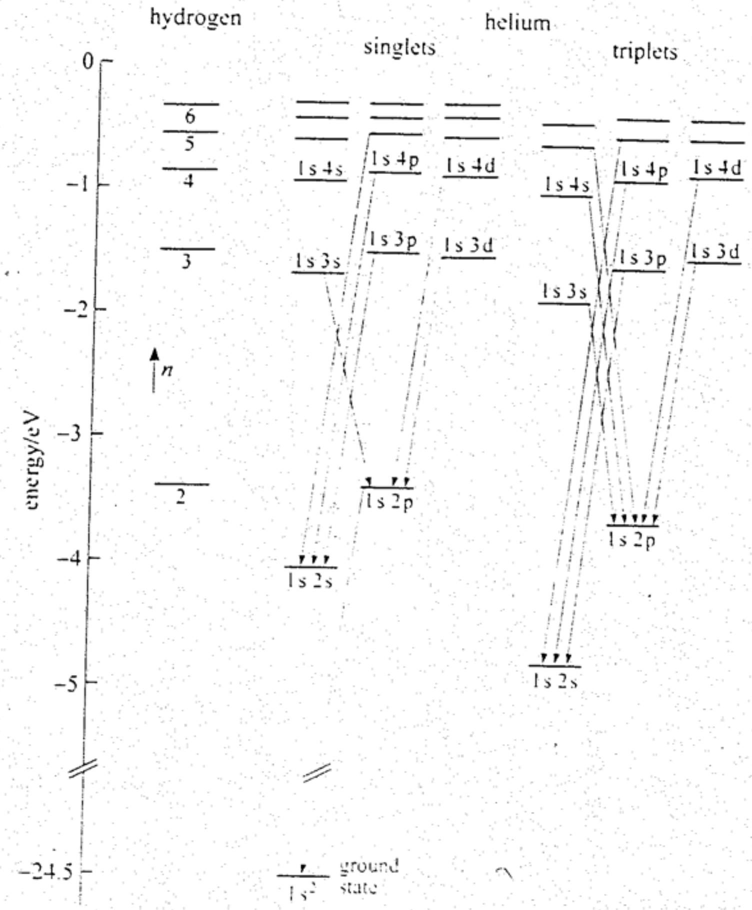

Figure 7 For use with Q25.

(i) Explain why the helium singlet 1s 2p level in Figure 7 is very close to the hydrogen $n = 2$ level, but the helium 1s 2s level is considerably lower.

(ii) Each of the helium triplet levels shown in Figure 7 consists of three separate levels too close together to distinguish in the figure. The helium singlet levels however are not split. Explain the origin of this effect.

(5 marks)