LECTURE 14

Content

Previously we have concerned ourselves with the energy states of an atom. In this lecture we will start to look at **transitions** between the states – transitions that are either *allowed* or *forbidden* by **selection rules**.

Outcomes

At the end of this lecture you will:

- know that transitions between states are governed by selection rules
- know that selection rules for a transition may be obtained from Fermi's Golden Rule
- be able to explain how the electric dipole selection rules arise from the properties of the spherical harmonics
- be able to apply the electic dipole selection rules to transitions between states to determine which are allowed and which are forbidden

LECTURE 14 SUMMARY

- transitions between states are governed by selection rules
- selection rules for a transition may be obtained from Fermi's Golden Rule
- the properties of the spherical harmonics determine the selection rules
- for an electric dipole transition the selection rules are: $\Delta l = \pm 1, \Delta m = 0, \pm 1, \Delta s = 0$, and the states must be of opposite parity. $\Delta j = 0, \pm 1$ (but not $j = 0 \rightarrow j' = 0$) if spin-orbit interaction is significant

LECTURE 15

Content

In this lecture we will begin to examine the interaction between an atoms (simplified to having just two energy levels) and a radiation field. We will introduce the processes of absorption, spontaneous emission and stimulated emission and derive the Einstein relations. We will discuss the lifetimes of excited states and the phenomenon of metastable states in preparation for a study of laser action.

Outcomes

At the end of this lecture you will:

- know and be able to describe the processes by which an atom interacts with a radiation field
- be able to derive the Einstein relations between the coefficients for absorption, stimulated emission and spontaneous emission
- know that an excited state has a finite lifetime that leads to a finite energy width
- know that if selection rules inhibit spontaneous decay the lifetime is extended and the state is metastable

LECTURE 15 SUMMARY

- an atom interacts with a radiation field via absorption, spontaneous emission and stimulated emission of a photon
- the Einstein relations may be derived by considering the equilibrium of the atom with the radiation field
- the excited state has a finite lifetime and finite energy (frequency) width
- an electric dipole forbidden transition has a longer lifetime, producing a metastable state

LECTURE 16

Content

In this lecture we will outline the conditions needed to obtain laser action. We will then describe a scientific application of lasers (and an example of research at UCL) – the cooling of neutral atoms.

Outcomes

At the end of this lecture you will:

- know that stimulated emission photons are coherent, and that this is the basis for laser action
- be able to describe the conditions necessary to achieve laser action in terms of a population inversion and metastable energy levels
- be able to explain how lasers may be used to cool atoms

LECTURE 16 SUMMARY

- photons emitted in stimulated emission are coherent, which is the basis of the laser
- to achieve laser action needs a population inversion
- this is not possible in a two-level system, so usually a three- or four-level system is used
- lasers can be used to cool atoms by carefully choosing their frequency to exert a velocity dependent force

LECTURE 17

Content

In this lecture we will look at the X-ray spectra of atoms that arises as a result of bombarding with energetic electrons.

Outcomes

At the end of this lecture you will:

- know that X-ray spectra are produced by the bombardment of a metal target by electrons
- be able to describe the principle feature of a typical X-ray spectrum
- know X-ray notation for the characteristic spectrum
- be able to calculate wavelengths of characteristic X-rays from atomic data

LECTURE 17 SUMMARY

- X-rays are emitted when a target of heavy metal atoms isbombarded by energetic electrons
- The typical spectrum consists of a continuous background of Bremmstrahlung with characteristic peaks superimposed
- The Bremmstrahlung has a short wavelength cut-off determined by the energy of the electrons, independent of the target material
- The peaks are caused by the removal of an electron from an inner shell and higher energy electrons making a transition to the inner shell by emitting an X-ray photon
- The wavelength of the peaks is characteristic of the target and can be calculated from a Rydberg-type formula when a screening constant is included

LECTURE 18

Content

In this lecture we will start to examine the effect of applying an external field (electric or magnetic) on an atom. We will commence with a study of the **Zeeman effect** at low magnetic field, and distinguish between the 'normal' and 'anomalous' effects, depending on whether spin must be considered.

Outcomes

At the end of this lecture you will:

- know that an atom interacts with a magnetic field through the magnetic dipole moment
- be able to treat this interaction in the perturbative limit
- be able to evaluate the effect in terms of a shift in energy levels and a splitting of spectral lines

LECTURE 18 SUMMARY

- the interaction between an atom and a magnetic field is called the **Zeeman effect**
- the magnetic field interacts with the magnetic dipole moments of the atom that arise from the angular momenta (spin and orbital)
- the interaction can be evaluated in the limit where it is a small perturbation
- if the interaction is smaller than the spin-orbit interaction is is classed as 'weak'
- the weak field Zeeman effect is classified as 'normal' or 'anomalous' depending on whether spin is needed to explain the effects
- the Zeeman effect splits a transition into a number of spectral lines

LECTURE 19

Content

In this lecture we will continue our study of atoms in external magnetic fields by examining the case of strong magnetic fields known as the **Paschen-Back** effect. We will investigate the effect of the transition from zero through weak to strong magnetic fields on the sodium Fraunhofer doublet.

We will then discuss an application of non-uniform magnetic fields in the **Stern-Gerlach experiment** which demonstrates the quantisation of spin. Lastly we will mention the magnetic moment that arises due to nuclear spin, and the **hyperfine splitting** due to its interaction with the magnetic field of the orbiting electron.

Outcomes

At the end of this lecture you will:

- be able to explain the splitting of spectral lines in strong magnetic fields (the Paschen-Back effect)
- be able to calculate these splittings and identify allowed transitions
- be able to describe the Stern-Gerlach Experiment and the evidence for the quantisation of atomic angular momentum
- know that the nucleus also possesses spin and that this leads to further splitting of energy levels referred to as hyperfine structure

LECTURE 19 SUMMARY

- in the limit of strong applied magnetic field spin and orbital angular momentum decouple and precess independently around the field direction
- m_l and m_s are thus good quantum numbers
- due to the electric dipole selection rules a single spectral line is split into three
- the Stern-Gerlach Experiment provides evidence for the quantisation of angular momentum
- the nucleus of an atom also possesses a nuclear spin $\underline{I}$, and magnetic moment $\underline{\mu}_I$
- $\underline{\mu}_I$ interacts with the magnetic field of the orbiting electron to split energy levels into hyperfine sublevels depending on their value of $F = I + J$

LECTURE 20

Content

In this lecture we will look at the effect of an external electric field on atomic energy levels, i.e. the **Stark Effect**. We will see that for the majority of atoms that do not possess an intrinsic dipole moment there is no change in energy to first order, and it is the electric dipole *induced* by the electric field that produces a shift that is **quadratic** in the electric field. A special case arises for the degenerate (in l and m_l) excited states of hydrogen which behave as though they have an electric dipole moment, and hence the energy change is **linear** in electric field.

Outcomes

At the end of this lecture you will:

- know that most atoms do not possess an intrinsic dipole moment
- know that their interaction with an external electric field is thus limited to the second order effect of the induced dipole
- be able to describe the energy change in terms of the polarisability of the atom and evaluate it from given data
- know that a special case is the excited state of hydrogen which is degenerate in l and m_l
- be able to compare and contrast linear and quadratic Stark effects

LECTURE 20 SUMMARY

- most atoms (with non-degenerate energy levels) have zero electric dipole moment and so their interaction with an electric field is zero to first order
- however an electric field polarises the atom to induce a dipole moment proportional to the applied field
- the interaction energy is thus quadratic in electric field, $\frac{1}{2}\alpha E_{ext}$
- an exception is the excited states of hydrogen that are degenerate in l and m_l
- an electric field mixes these states to produce an energy shift linear in E_{ext}