University of Nottingham
Nanoscale and Microscale Research Centre

An introduction to X-ray photoelectron spectroscopy

Dr Emily Smith

emily.smith@nottingham.ac.uk

Summary of X-ray photoelectron spectroscopy (To start with….)

X-rays excite electrons from a material **surface**.

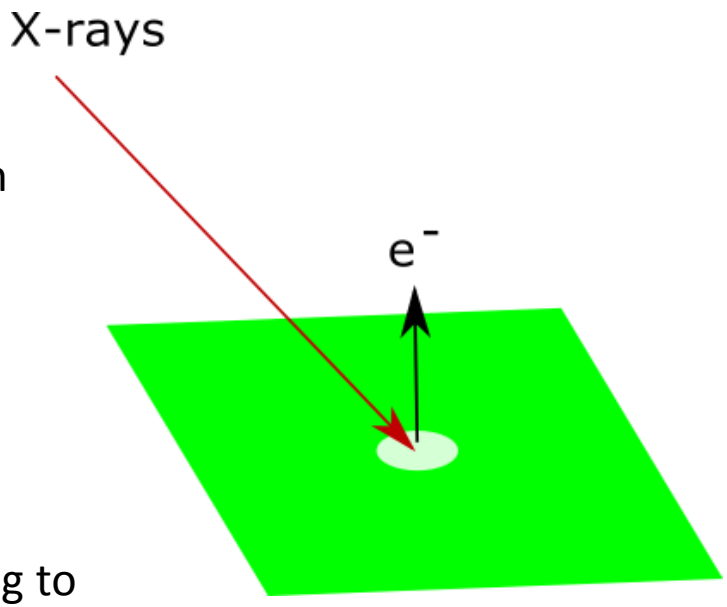
All elements (except H)

The electron energy depends on the elemental electron orbital binding energies.

Calculate atomic%

Calculate layer thicknesses

Small shifts in the binding energies are cause by bonding to different other atoms, so the ‘oxidation state’ of the atoms can sometimes be determined from the shifts. (‘chemical shifts’)



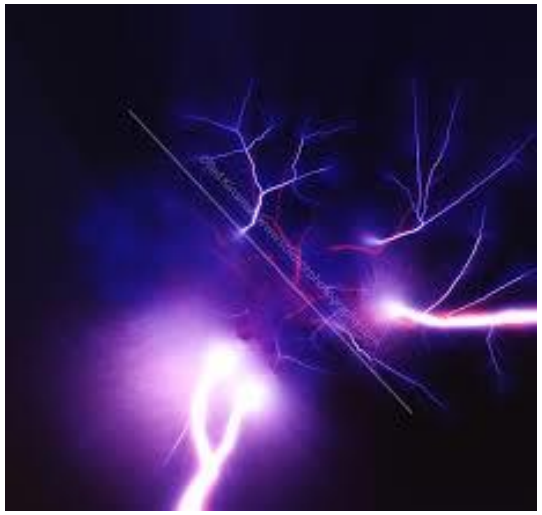
Talk outline

History of X-ray photoelectron spectroscopy
Basic principles behind XPS
Resources – instruments, people, software and information
Sample types, sizes and how they are put into XPS instruments
An example – basic spectral features
How a simple quantification works

More spectral features
Peak shapes: single peaks, doublets, and extra complexity.
The Auger parameter.

Some examples:
Review atomic % on simple
Silicon oxide –
Peaks of increasing complexity Si 2p, Ni 2p and Ce 3d
Some key equations
Additional ways to do XPS experiments

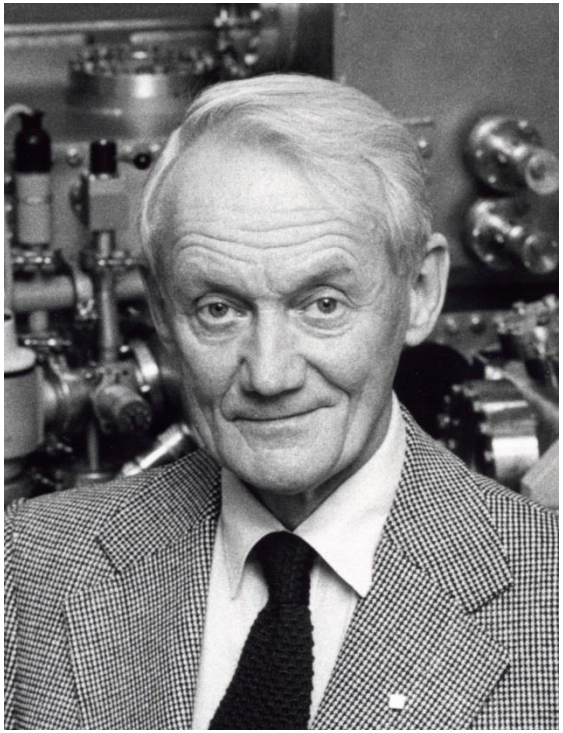
History of XPS



~ 1887 Heinrich Hertz
Observed UV irradiated electrodes emitted more sparks .

Albert Einstein received the Nobel prize in physics for explaining the photoelectric effect. (1921)

History of XPS



Whilst waiting for parts to do something completely different, Kai Siegbahn used his Ultra-high vacuum spectrometer to observe photoelectrons generated by X-rays. (~1967) He received a Nobel prize for this in 1981.

He called the newly developed technique Electron Spectroscopy for Chemical Analysis (ESCA)

History of XPS

Stainless steel, modular ultra high vacuum systems were developed.

Manufacturers made mono-chromated systems,

Peaks were printed onto graph paper and their positions and intensities measured manually with rulers, scissors and weighing scales.

In the early 1980's computers started to make data collection easier.

VMS data format was invented so all data could be compared

CASAXPS developed (~1999?) – other data processing software is available.

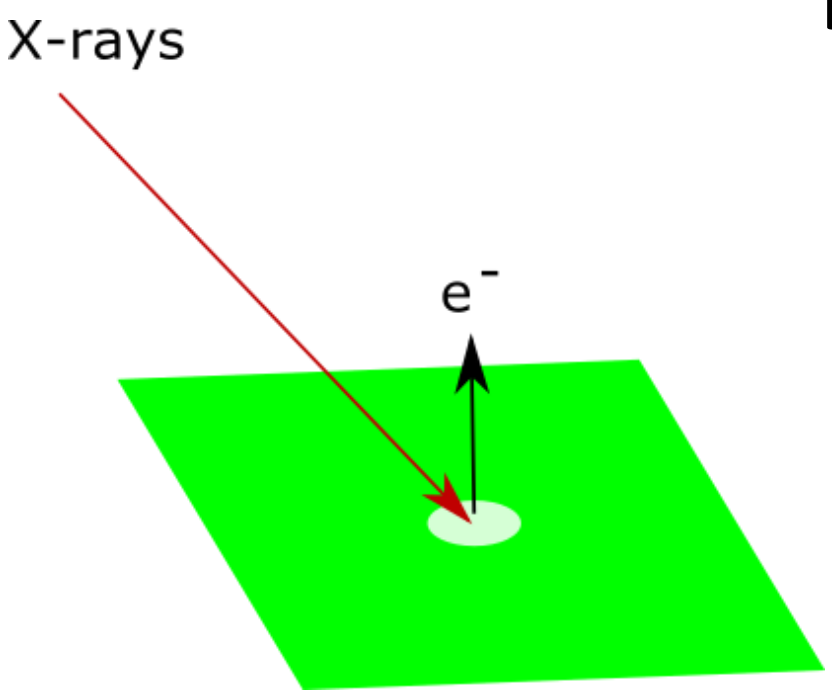
After that we started having to be clever about interpreting the spectra. Over the last 20 years the internet has provided readily accessible information which has improved interpretation.

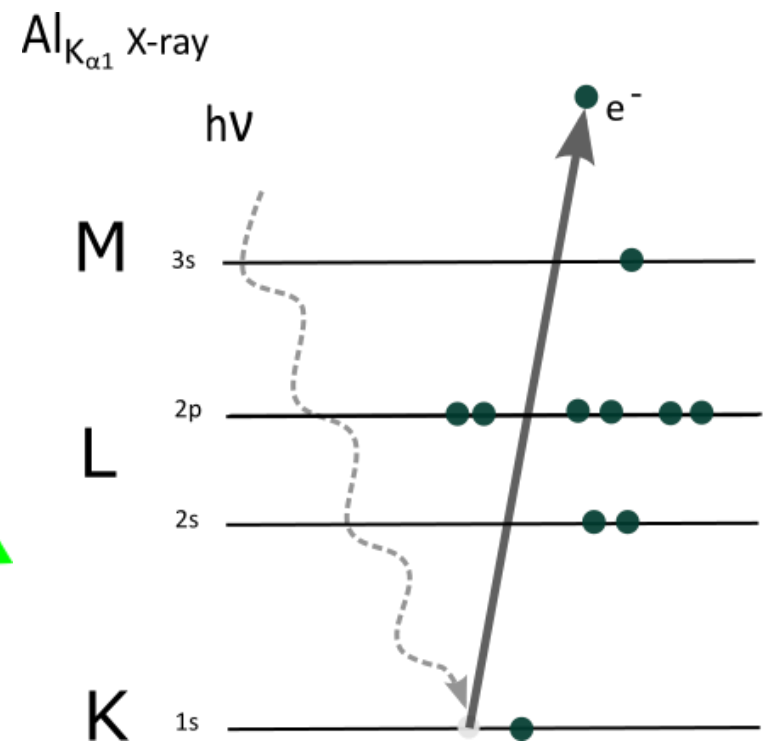
Basic principles of XPS

Basic principles of XPS

X-ray Photoelectron Spectroscopy

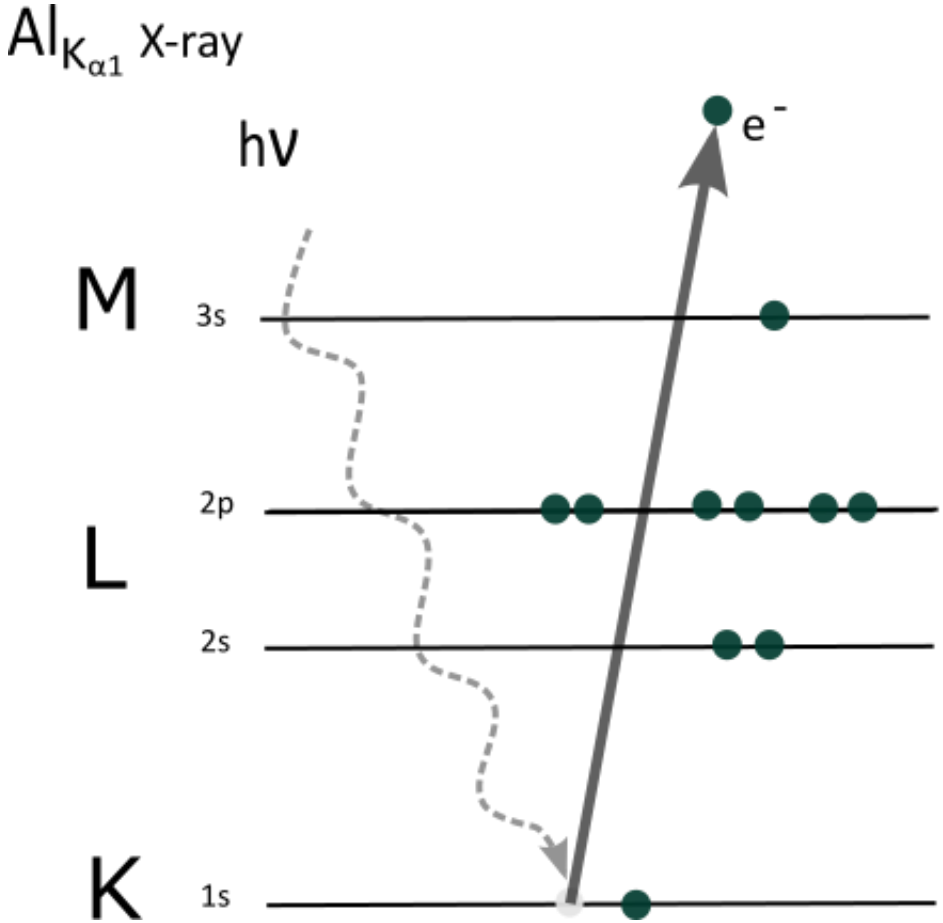
$$KE = h\nu - BE - \phi$$





Basic principles of XPS – X-rays excite photoelectrons

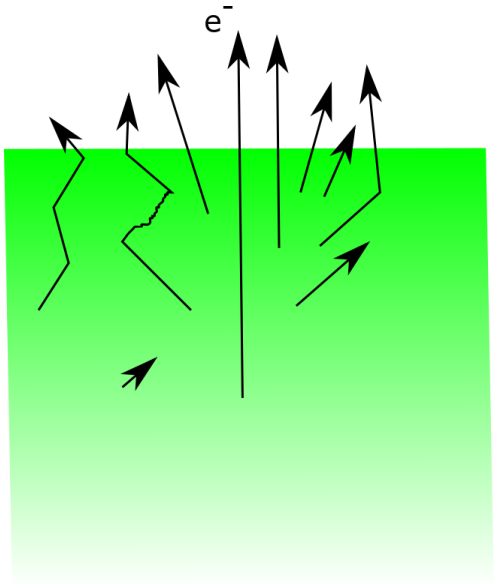
The photoelectron peak intensity depends on how many atoms are emitting from the surface and how sensitive that orbital is to X-rays of a particular energy.



Cross sections / Relative sensitivity factors

Basic principles of XPS – Why is this a surface technique?

$$KE = h\nu - BE - \phi$$



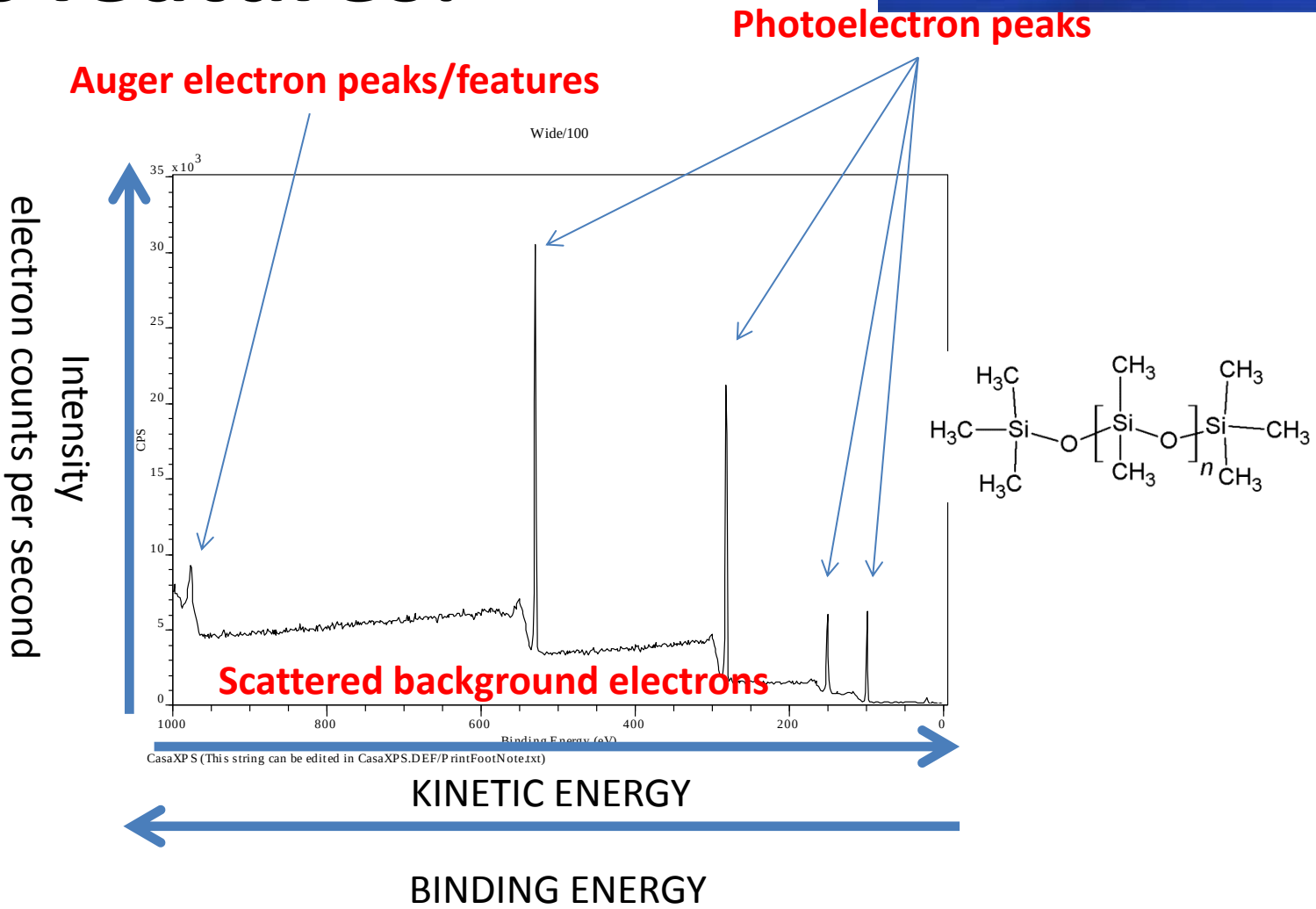
The X-rays that excite photoelectrons are low energy. (1.5 keV, medical X-rays, for comparison are ~ 60 keV)

So the excited photoelectrons are relatively slow and mostly interact with the material they are generated and lose energy.

- A few electrons get out un-scattered and are detected as the photoelectron peaks. (mostly from the upper 10 nm of the material.)
- Many more get out of the surface but have lost energy so make up the detected scattered background
- The vast majority don't get out and are not detected.

An example XP spectrum

Basic features:



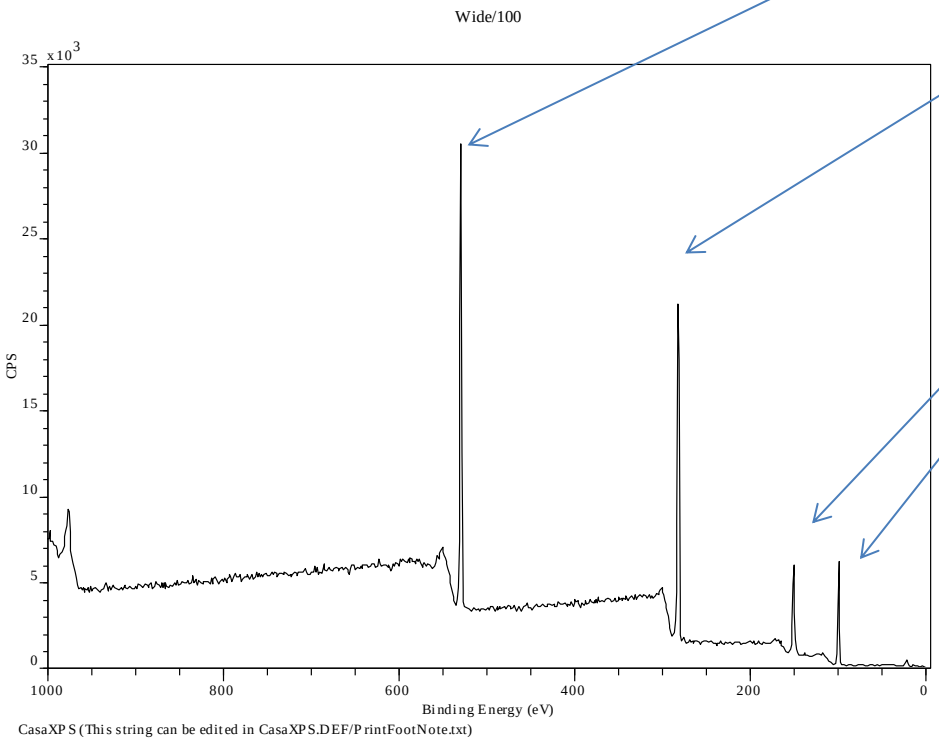
XP spectral information

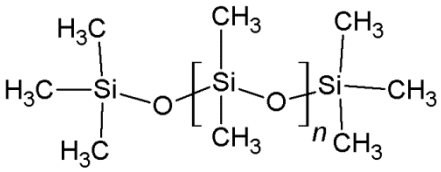
Identify the elements using
Their peak binding energy

Oxygen

Carbon

Silicon

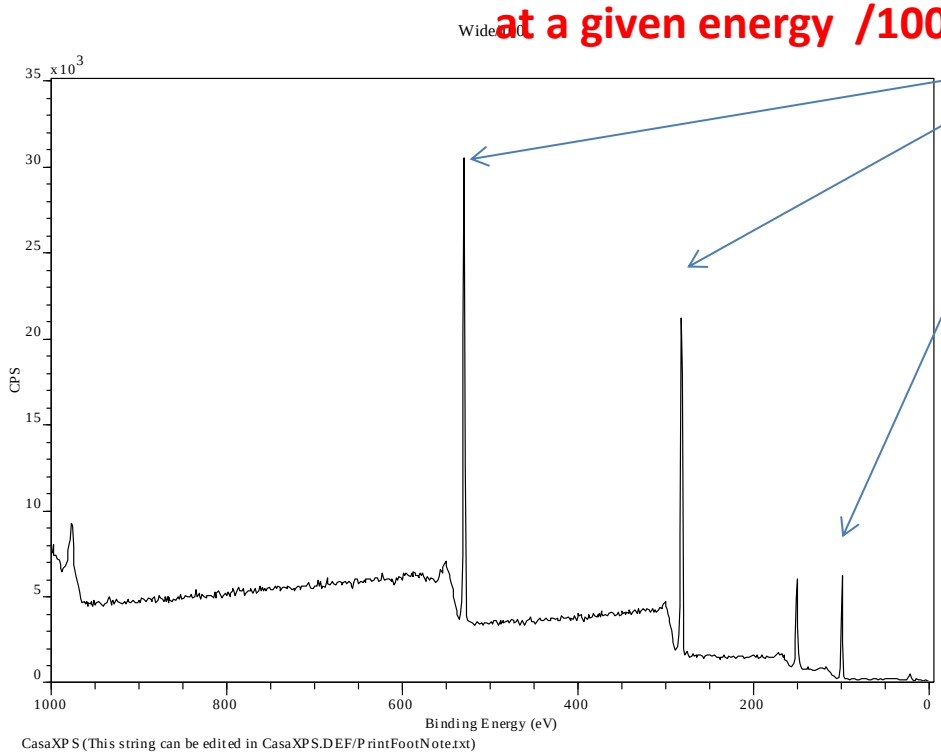




XP spectral information

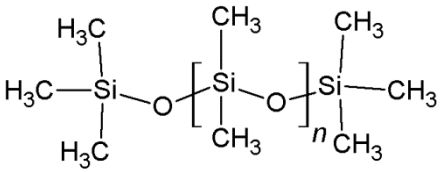
Quantify the elements based on peak intensity (area)

All photoelectron peak areas normalised by a 'sensitivity factor' and a 'transmission function' for the instrument at a given energy /100%



Calculate atomic %

25 at% oxygen
25 at% silicon
50 at% carbon



Note: Just one peak or doublet per element

No Hydrogen

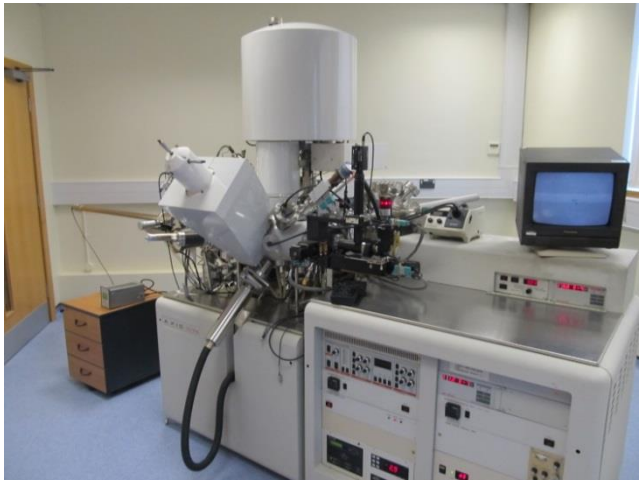
Resources:

Instruments,

Experts (People),

Software,

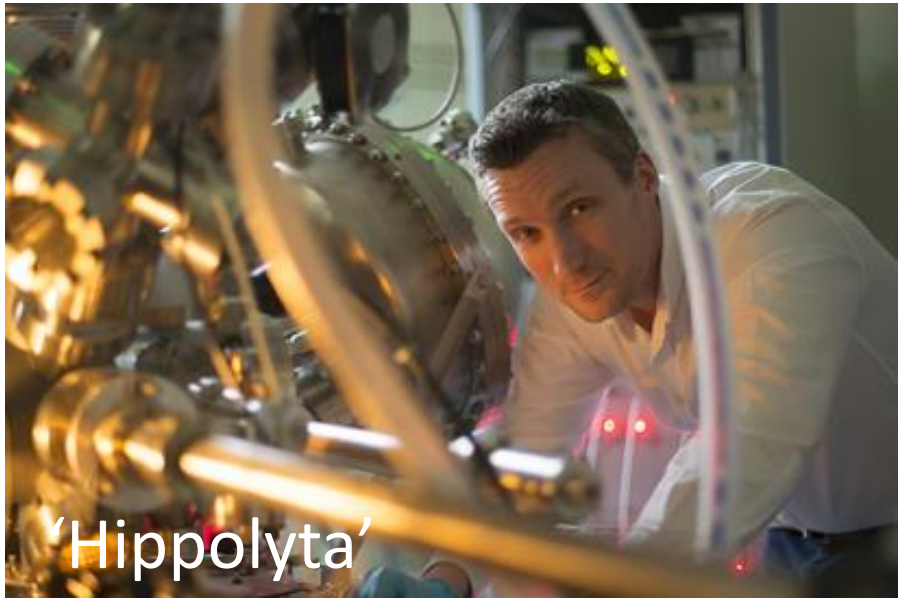
Information - databases and books



Kratos Axis Ultra - XPS1, B16 NMRC

Kratos Axis Ultra
LiPPS , B16 NMRC

Specs High pressure XPS
(Near ambient pressure XPS)
Physics



James O'Shea

VG ESCA Lab, Wolfson Building

University of Nottingham
Nanoscale and Microscale Research Centre

XPS instruments in NMRC

Emily Smith
Craig Stoppiello

NAP-XPS

James O'Shea
Robert Temperton

Data processing and advice on experiments: Ana Santos, Jesum Fernandez, Nigel Neate, Martin Roe,

How to book XPS time in NMRC

- Use Stratocore (PPMS): Apply for ‘training’ (~1/2 hour discussion of samples)
- Book approx. 1 hour session per sample for simple spectroscopy, contact Emily or Craig for more complex work.
- Bring samples in <u>labelled</u> containers with MSDS if required.

Specialist XPS data processing software at Nottingham

www.casaxps.com

CasaXPS

Copyright © 2015 Casa Software Ltd

CasaXPS:

CasaXPS processing software offers powerful analysis techniques for both spectral and imaging data. The system originally designed for XPS an

For further information, please contact neal@casaxps.com.

日本語は、こちら For information in Japanese, please click here.

www.quases.com/home/

Home About Products How to Order

QUASES

Software packages to characterize surface nano-structures by a

References

Overview of software packages

QUASES-Tougaard
for quantitative XPS or AES analysis of three dimensiona

QUASES-ARXPS
for quantitative angle resolved analysis by XPS or AES fr

QUASES-XS-REELS
for quantitative determination of the effective inelastic ele

QUEELS-ε(k,ω)-REELS
software to determine the optical and dielectric properties

QUASES-IMFP-TPP2M (free)
for calculation of inelastic electron mean free paths by th

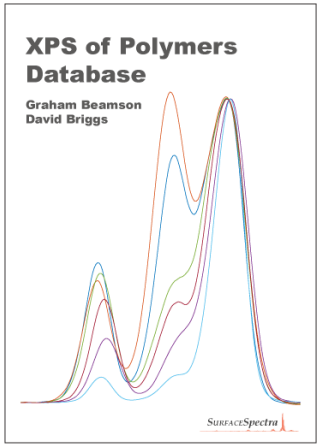
QUEELS-XPS (free)
software to calculate the energy loss structure caused by XPS (i.e. it calculates the intrinsic and extrinsic effects). T electron configurartion.

QUASES-Simple-backgrounds (free)
for peak intensity determination using different backgrou

University site licence: can download at any time

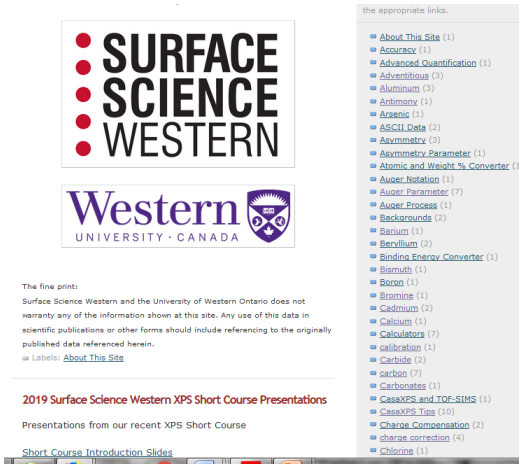
Single seat licence: ask Emily

Databases and websites



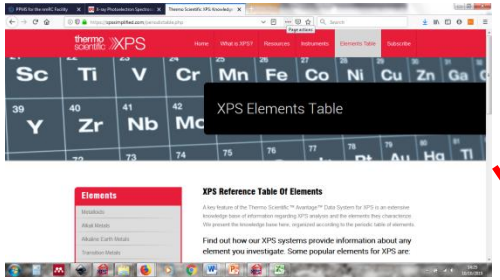
For anything polymer-like The XPS of polymers database, by Beamson and Briggs is ideal. Providing detailed spectra in vms format for comparison as well as peak shifts for carbon from aliphatic carbon at 285 eV

For inorganic materials, transition metals and pretty much anything else there is an excellent website 'XPSfitting' which is run by Mark Beisinger at the University of Western Ontario, Canada.

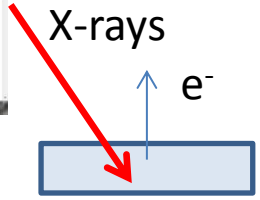


http://www.xpsfitting.com/

Another good website is XPSsimplified run by Thermoscientific which has information for each element in periodic table form.

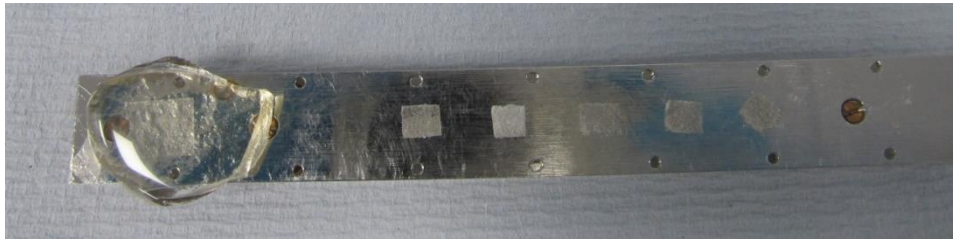


https://xpssimplified.com/periodictable.php



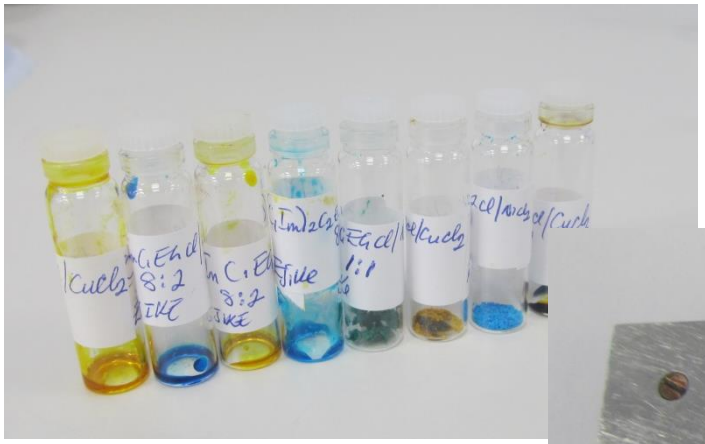
Samples: type, size and shapes

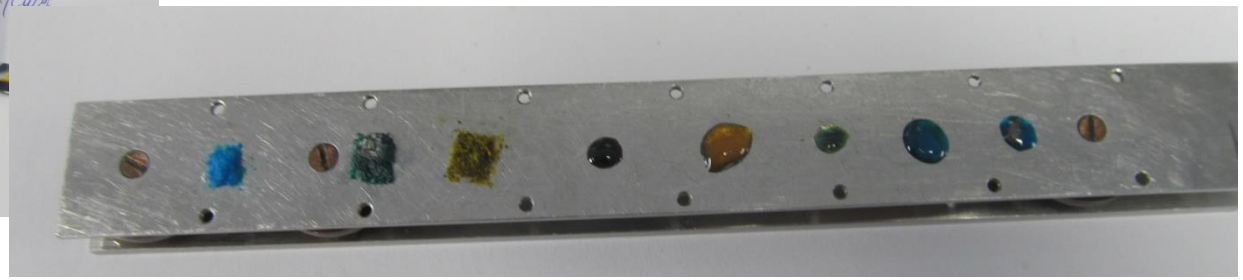
Kratos sample bars ~ 12cm x 1.5 cm usable space



Solid powders
Larger blocks
Ideal size ~ 1cm square and flat

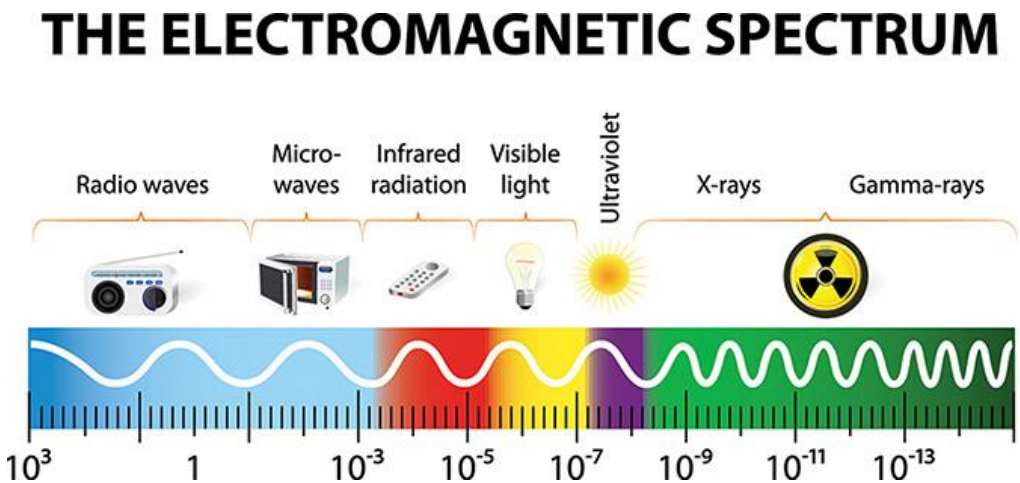
All elements
(except H)





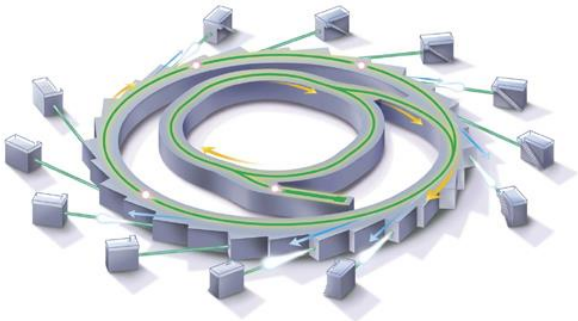
Most liquids will evaporate in the vacuum system, ionic liquids with low vapour pressure are possible

Basic principles of XPS –Excitation sources

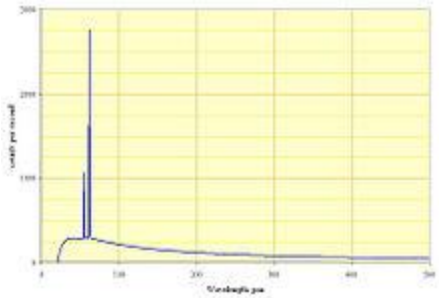


Synchrotrons – tuneable X-ray energies

10 eV – 15,000 eV



Lab based 'fixed' X-ray sources



Typically
1,000 – 5,000 eV

Ultraviolet sources – (UPS)

10 – 121 eV, most commonly lab based sources are
He I (21 eV) and He II (41 eV)

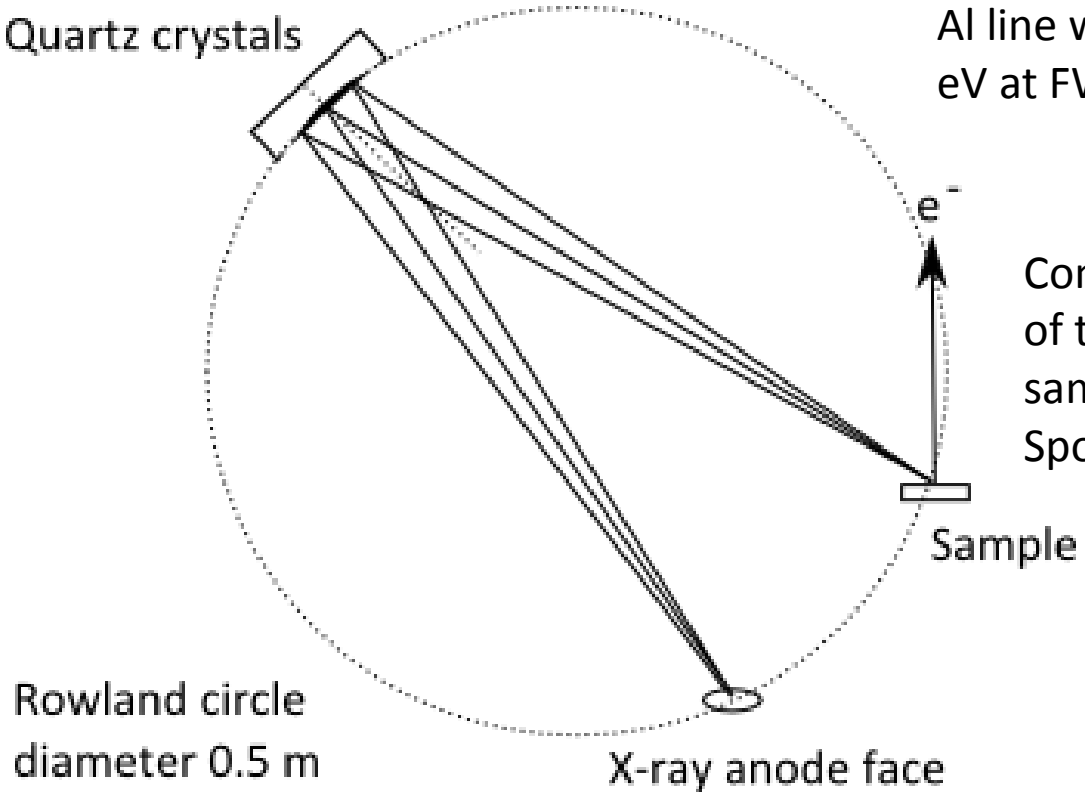
Basic principles of XPS –Excitation sources

Lab based ‘fixed’ X-ray sources

Anode	Radiation	Photon Energy (eV)	Line Width (eV)
Mg	Kα	1253.6	0.7
Al	Kα	1486.6	0.85
Zr	Lα	2042.4	1.6
Ag	Lα	2984.3	2.6
Ti	Kα	4510.9	2
Cr	Kα	5417	2.1

Basic principles of XPS –Monochromation

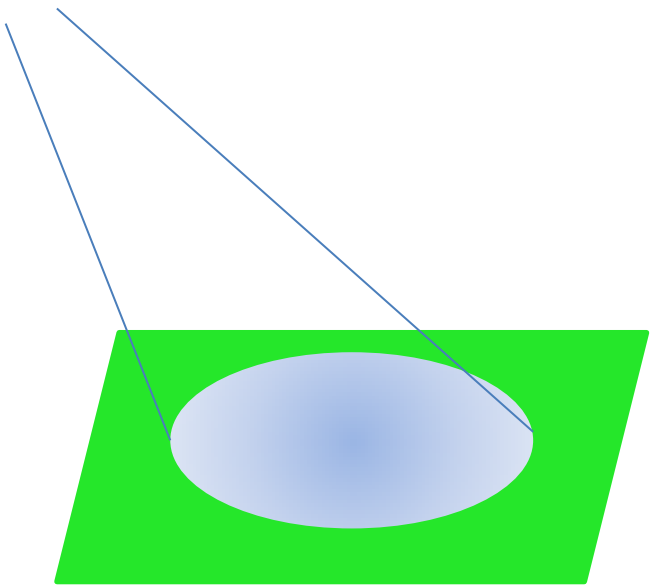
Lab based 'fixed' X-ray sources – mono-chromating



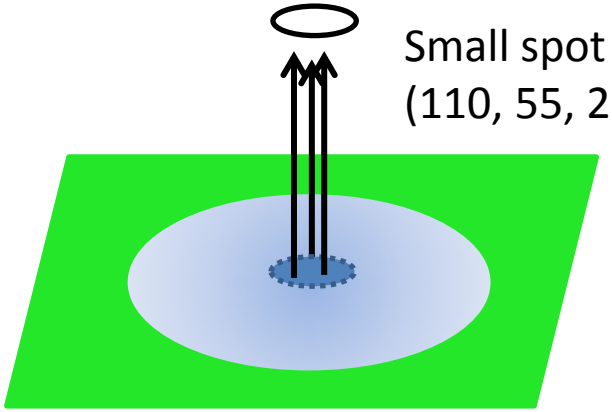
Al line width goes from 0.85 eV at FWHM to 0.16 eV

Constructive interference of the Al Kα X-rays at the sample
Spot size is ~ 1 mm

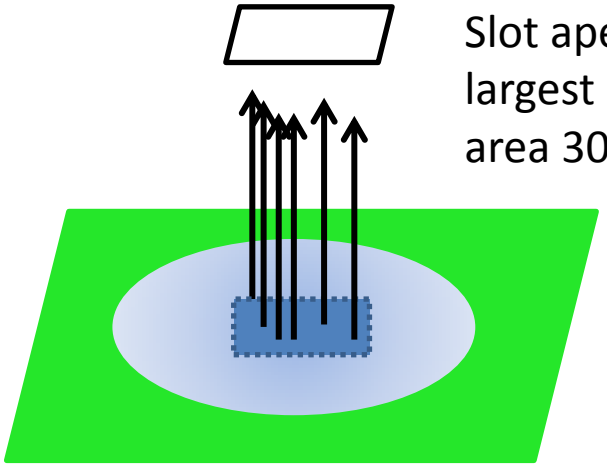
Basic principles of XPS – Area of analysis



X-ray spot ~ 1mm



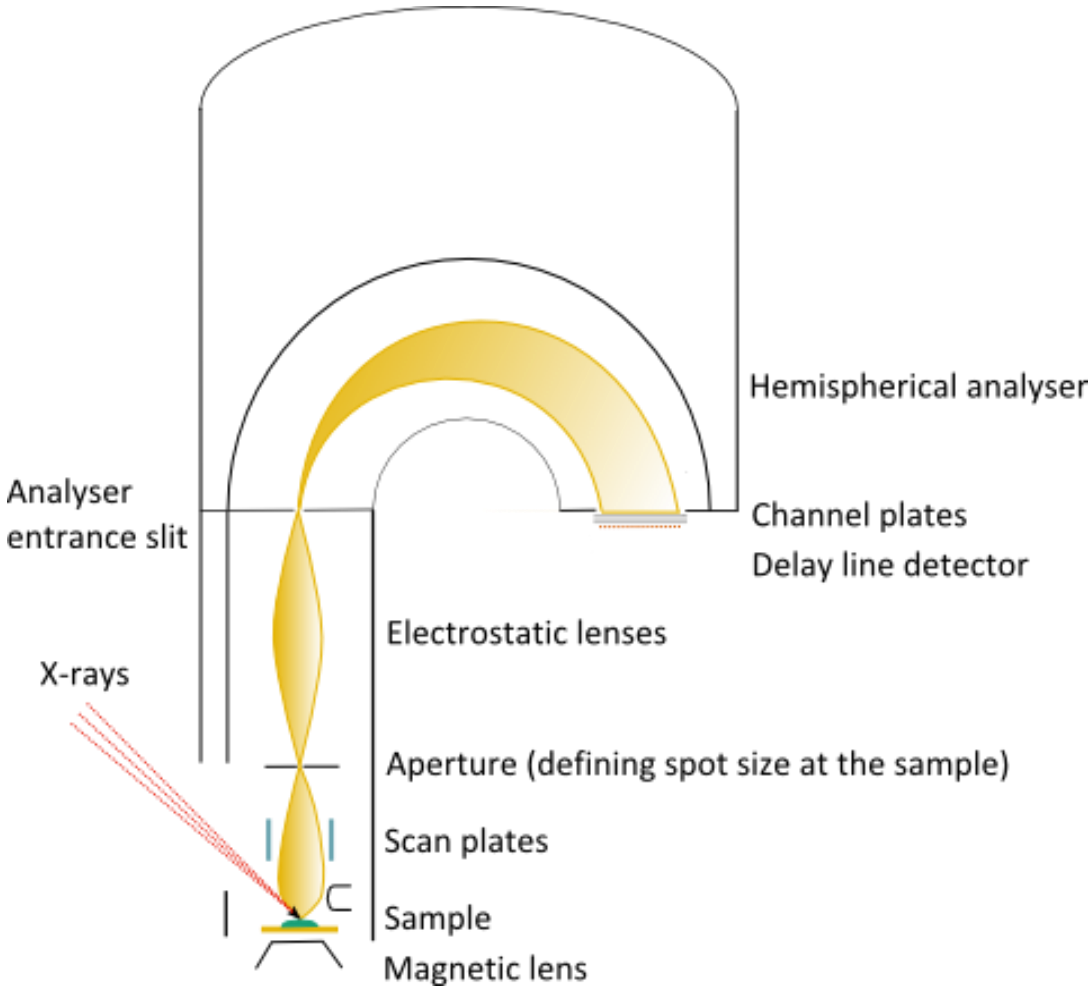
Small spot apertures (110, 55, 27 µm)



Slot aperture – largest collection area 300 x 700 µm

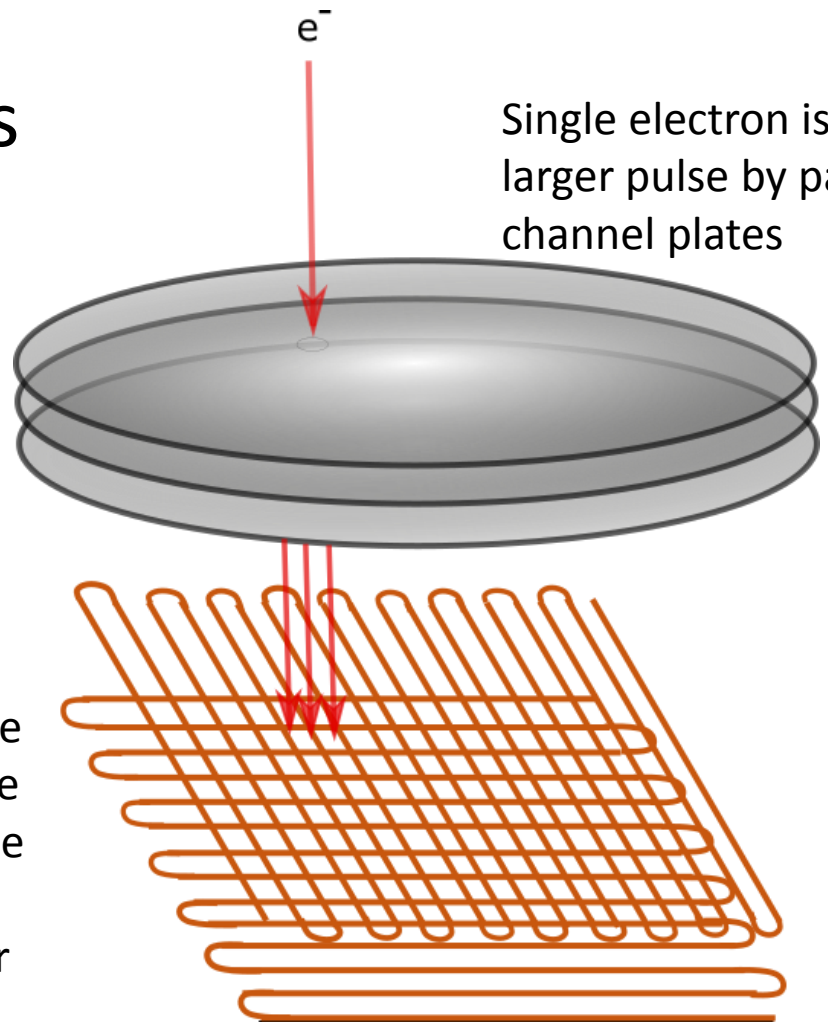
Electron collection area is smaller, and defined by an aperture in the lens column.

Basic principles of XPS –Electron collection



Basic principles of XPS –Electron counting

Channel plates and delay line detector



Single electron is multiplied to a larger pulse by passing through the channel plates

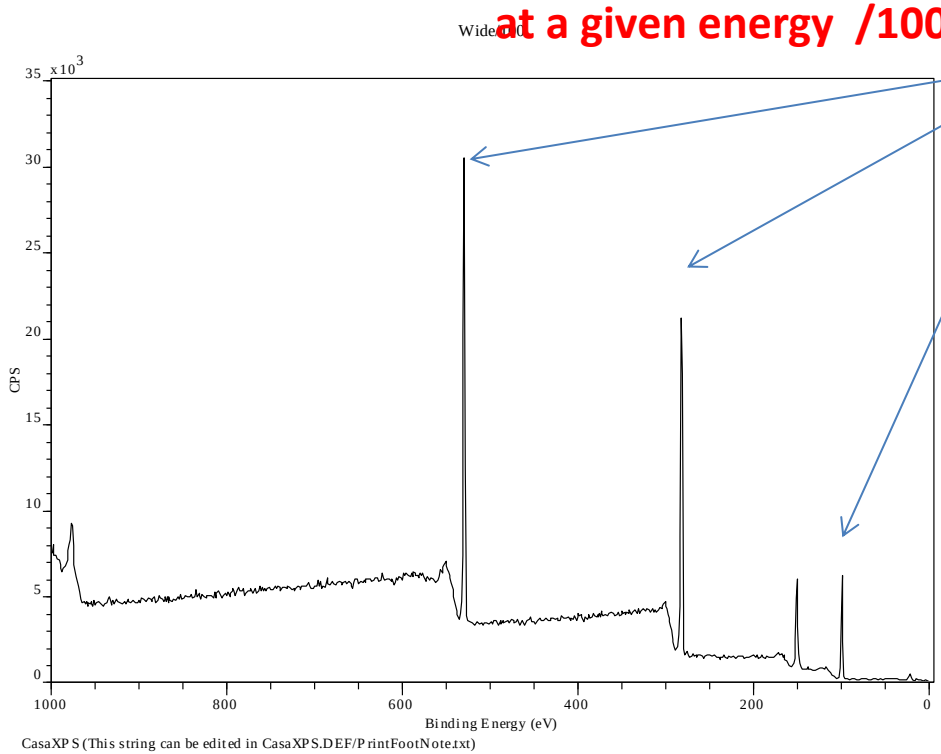
Copper wires detect the pulse of electrons, the timing of the pulse on the wires defines the position and therefore the energy at each delay line – or spatial position in imaging mode.

An example spectrum (Repeat!)

XP spectral information

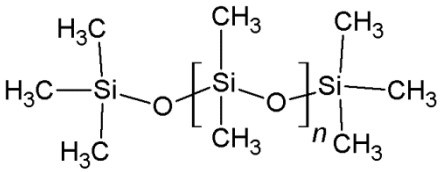
Quantify the elements based on peak intensity (area)

All photoelectron peak areas normalised by a 'sensitivity factor' and a 'transmission function' for the instrument at a given energy /100%



Calculate atomic %

25 at% oxygen
25 at% silicon
50 at% carbon



Note: Just one peak or doublet per element

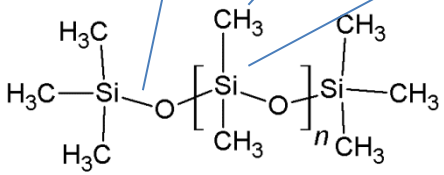
No Hydrogen

The basis of XPS quantification

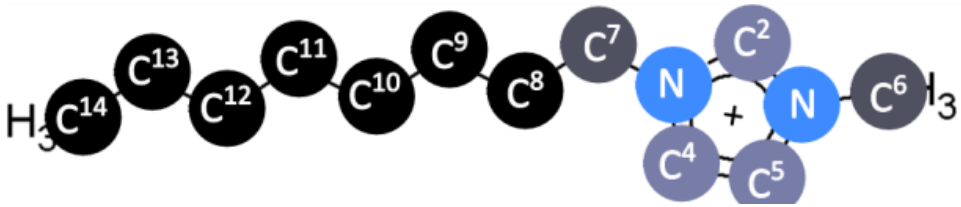
Total Atoms =

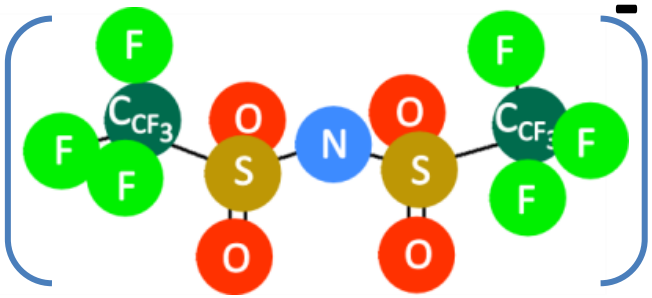
$$\sum_{1}^{n} \left(\boxed{}_{1} / RSF_{1} \, x \, TF_{1} \right) + \left(\boxed{}_{2} / RSF_{2} \, x \, TF_{2} \right) \; \ldots\ldots\ldots\ldots$$

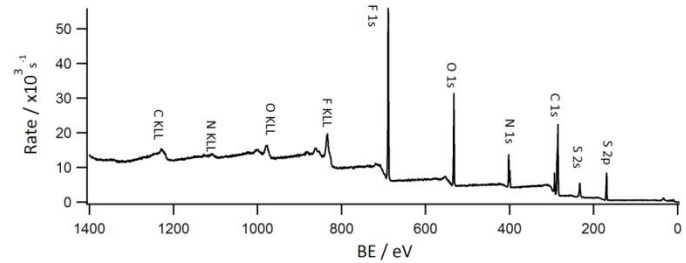
100%

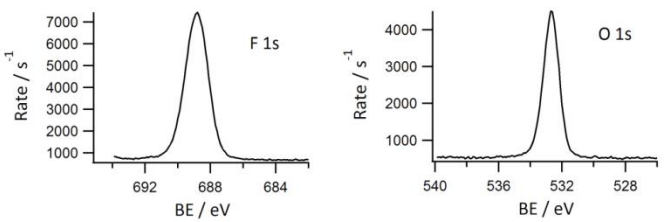


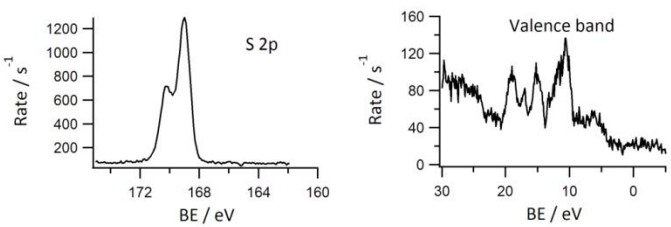
Quantifying the elemental composition of $[C_8C_1im]$ $[Tf_2N]^-$





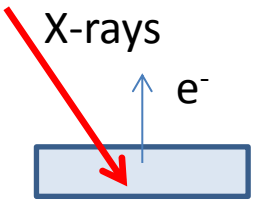




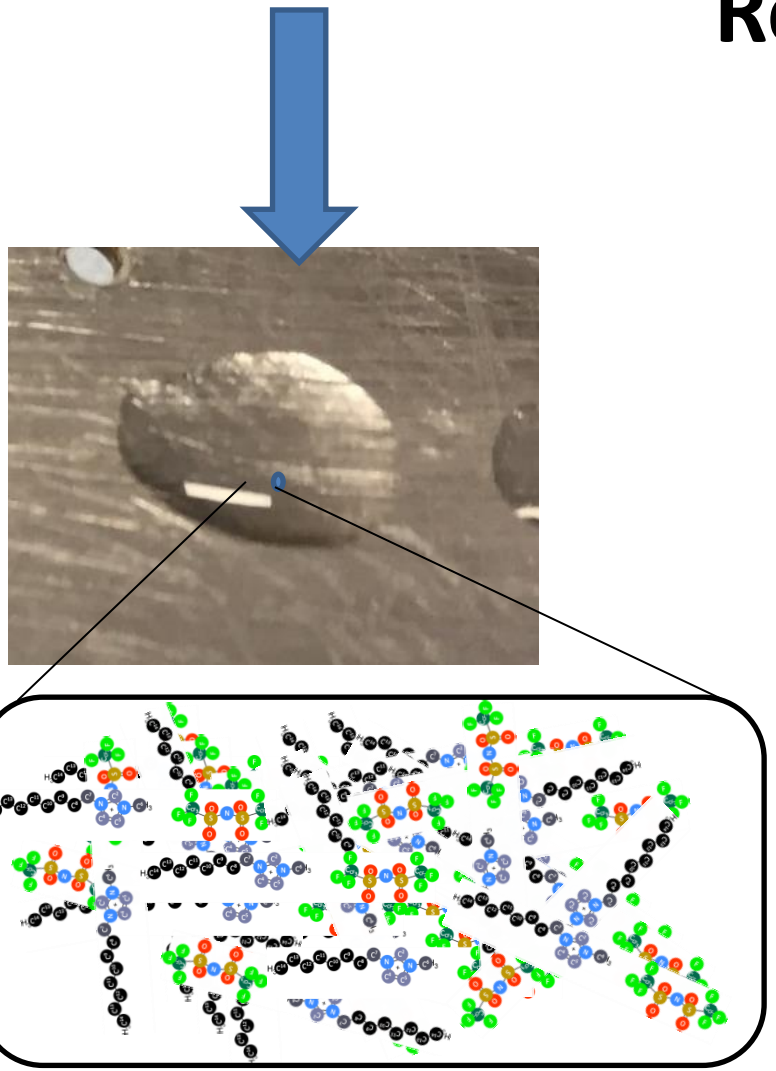


14 Carbon atoms (= 14/29)= 48.3 atomic%
3 nitrogen atoms = 10.3 at%
4 oxygen atoms = 13.8 at%
2 sulphur atoms = 6.9 at%
6 fluorine atom = 20.7 at%

29 atoms in total (detected)

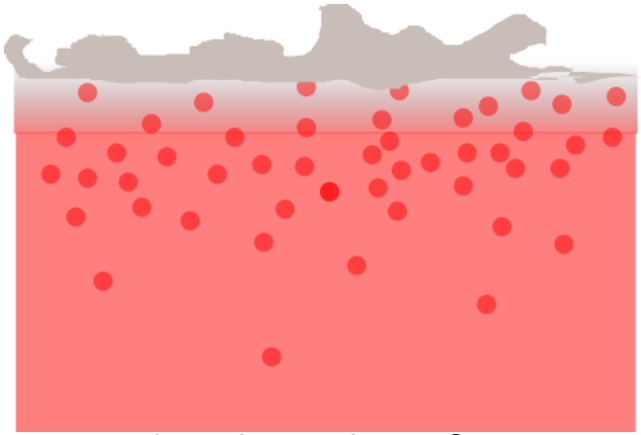


Quantification calculation assumes



Pure, homogeneous mixture

Reality is more like this



Layered and rough surfaces
with adventitious carbon/oxygen
And gradients of elements in alloys

More spectral information

Using XP spectral information

More information is available!

Photoelectron peak intensities for quantifications

Spin orbit splitting

Chemical shifts – origin and peak modelling

Auger peaks shifts and the Auger parameter

Multiplet splitting

The valence band

Shake up features

Charging shifts

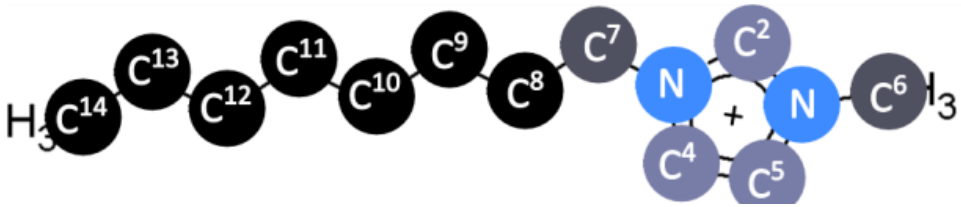
Surface and bulk plasmon losses

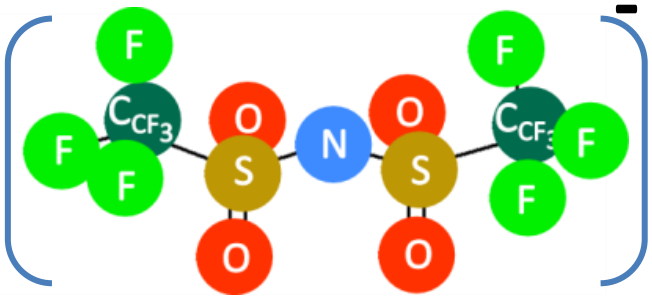
Kinetic energy effects

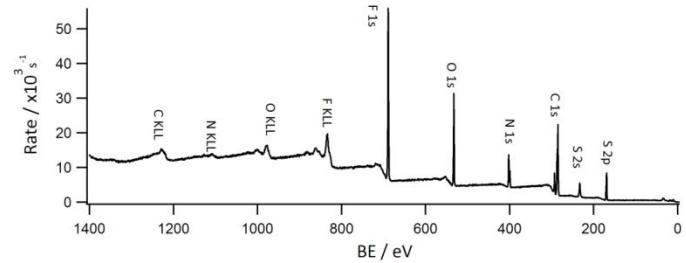
Inelastic mean free paths for film thickness measurements

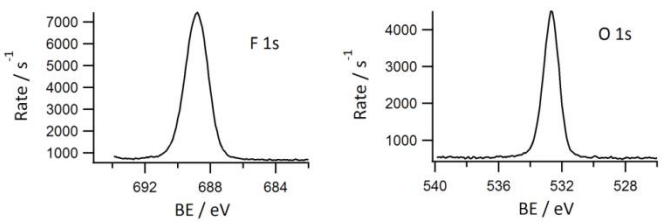
Using the scattered background to understand the sample structure

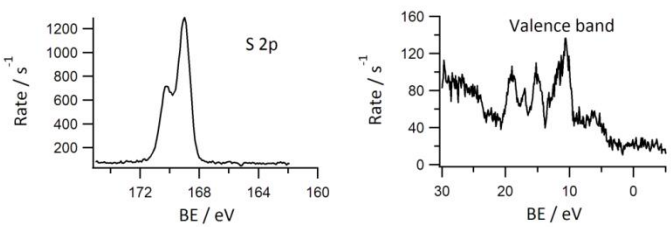
Quantifying the elemental composition of $[C_8C_1im]$ $[Tf_2N]^-$





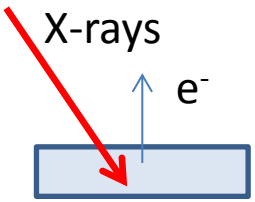






14 Carbon atoms (= 14/29)= 48.3 atomic%
3 nitrogen atoms = 10.3 at%
4 oxygen atoms = 13.8 at%
2 sulphur atoms = 6.9 at%
6 fluorine atom = 20.7 at%

29 atoms in total (detected)

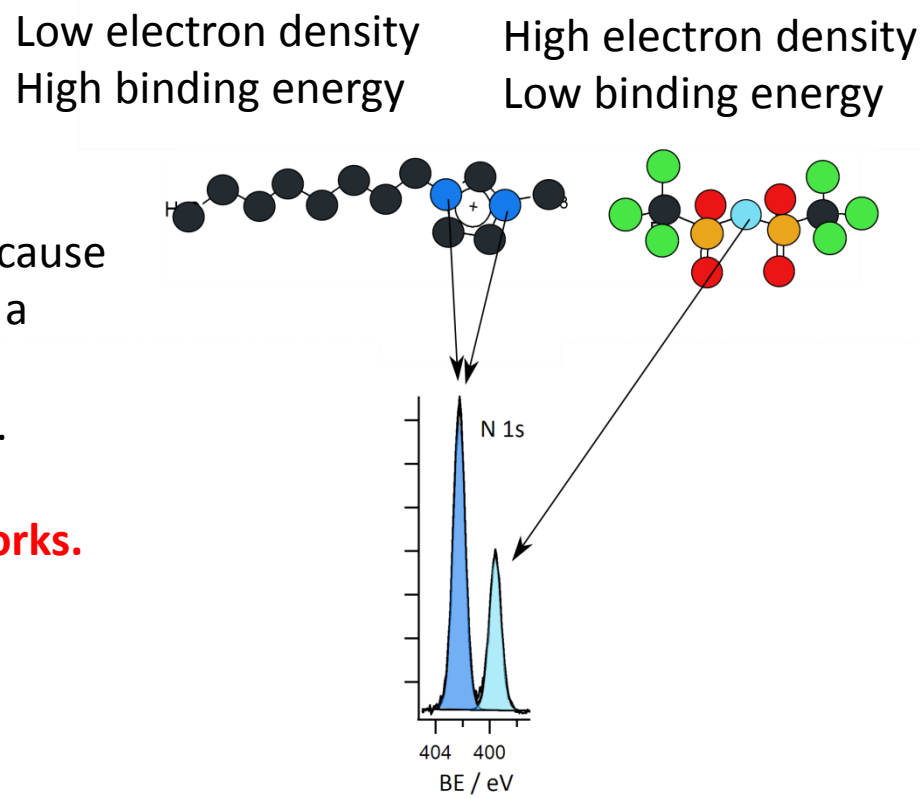


Chemical shifts – origin and peak modelling

When an atom is in a material it will be bonded to other atoms. These will effect the electron orbitals depending on how electronegative (electron withdrawing) the surrounding atoms are.

A surfeit of electron density around an atom will cause the inner electrons to have a low binding energy, a dearth of electrons will lead to an increase in the binding energy of all of the electrons in the atom.

The description above is a simplification…but works.

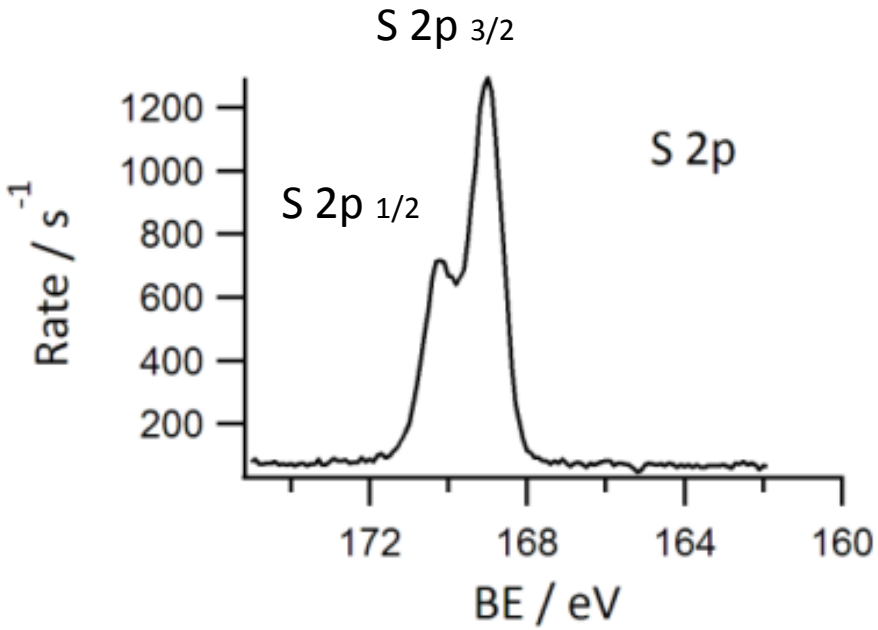


Spin orbit splitting / doublets

This is a **final state effect** due to coupling of the unpaired electron spin with the orbital angular momentum having two possible energy states .

So there is no energy split in the orbitals until you have photo-excited the electron out of it…but we still detect the splitting because the coupling reaction is fast relative to the photoelectron emission.

A little bit of physics:
There are two ways this is modelled/explained, for light elements 'l-s 'coupling of the individual electron with the orbital is simplest, as the atomic number increases the total angular momentum of all electrons provides a better model so a 'j-j' coupling model is used.



Spin orbit splitting – and what do the peak labels mean?

From the inner orbitals outward the photoelectron peaks are labelled 1s, 2s, $2p_{3/2}$, $2p_{1/2}$, 3s, $3p_{3/2}$, $3p_{1/2}$, $3d_{5/2}$, $3d_{3/2}$ *etc.*

These relate to the energy of the electron orbital in the atom.

'**n**' principle quantum number (the orbital)

2 p 3/2

'j' the total angular momentum number = | **l** +/- **s** |

Where 's' is the spin +/- ½

'**l**' the orbital angular momentum 'number'
confusingly this is a letter…….
s = 0, p = 1, d = 2, f = 3

Spin orbit splitting

General rules for dealing with spin-orbit splitting

You never get one part of a doublet without the other

The ratio of areas will be fixed (see table)

The energy split between the doublet is also fixed so if chemical shifts occur both peaks move together.

The energy split tends to increase with increasing Z (atomic number)

The widths may not be exactly the same – usually the higher BE peak is broader.

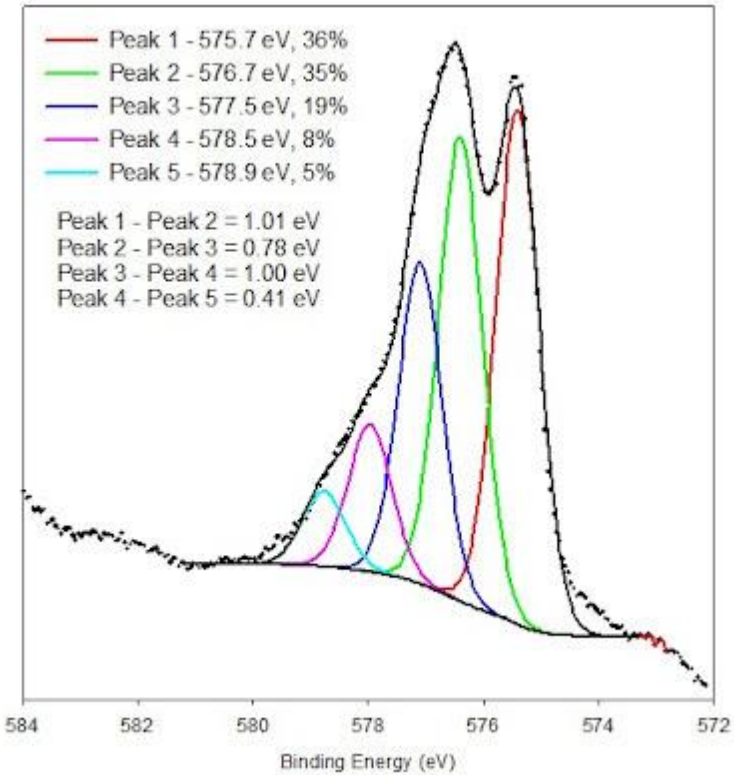
Orbital	Ratio of areas	In casaXPS
s (0)	-	-
p (1)	2:1	B=A*0.5
d (2)	3:2	B=A*0.666
f (3)	4:3	B=A*0.75

Multiplet splitting

Multiplet splitting is caused when some oxidation states of atoms leave unfilled outer shells. In a similar manner to spin-orbit splitting there are extra energy levels created due to the coupling of the unpaired electron with these. This is a **FINAL STATE EFFECT.**

Multiplet peak splitting tends to be seen in the heavier elements.

The resulting peak structures can be very complex, but often the overall shape can be used to directly diagnose the oxidation states.



Cr 2p 3/2 peak in Cr_2O_3 exhibiting multiplet splitting. (Taken from XPSfitting website c/o Mark Biesinger)

Initial and final state effects on real and measured binding energy

The Einstein equation assumes that the measured binding energy was the original energy of the electron in it's orbital before excitation. This is a 'frozen orbital' approximation.

$$\mathbf{KE = h\nu - BE - \phi}$$

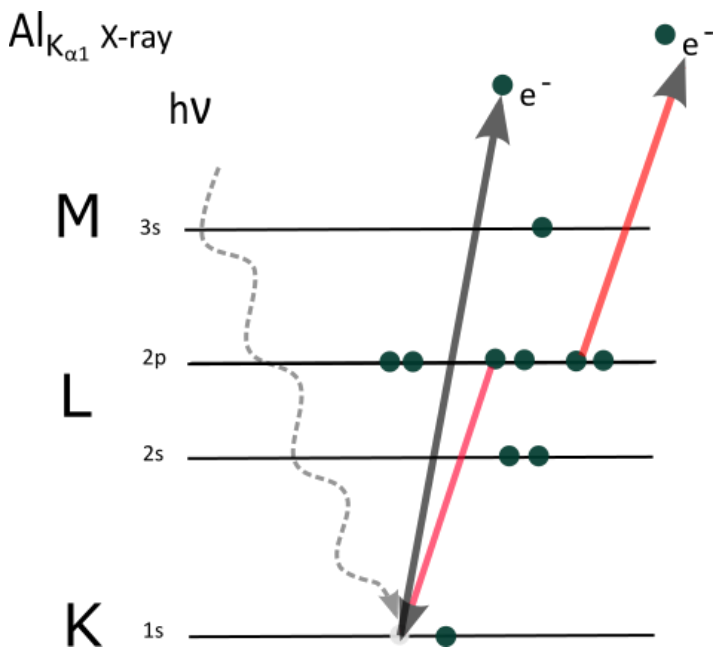
In reality, once a photoelectron is removed the ionized atom will 'relax'.
Some of the other electron orbitals will change energy and 'shield' the newly developed hole. This will be inter-atomic and intra-atomic within the lattice. This imparts extra KE to the exiting electron and the measured BE is therefore lower than expected. (up to 10 eV less according to calculations)

Luckily, this relaxation process within the atom is of similar magnitude for all oxidation states of the atom, so any shift in the unperturbed initial BE state is equally reflected in the final state and measured BE. - which is why the 'chemical shift' usually works as an approximation

Models : Koopmans (Frozen orbital),
Hartree – Fock – Slater.

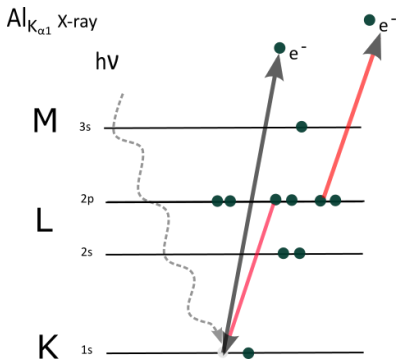
Auger electrons– and what do the peak labels mean?

Auger electrons are emitted after the photoelectron, as the atom de-excites. The atom becomes doubly ionised.

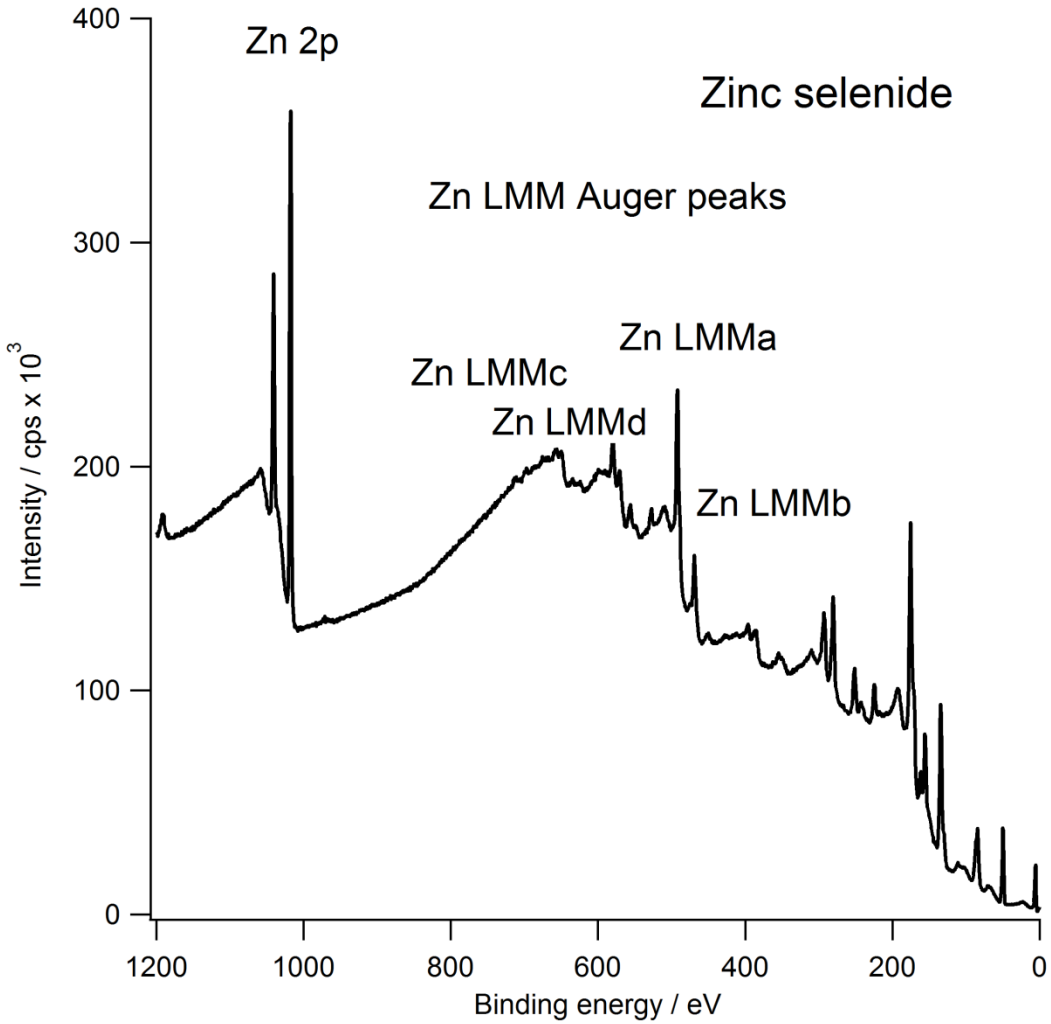


KLL and MNN come from 'X-ray' notation, which are ways of labelling the electron orbitals involved in the transitions.

Auger peaks and the (modified) Auger parameter



Auger peaks tend to be more complex than the photoelectrons peaks because they arise due to electron transitions from and to three different orbitals.
(KLL, LMM *etc.*)
Sometimes when the photoelectron peaks do not exhibit a strong chemical shift the Auger peak movement relative to the photoelectron peak can be used to work out the chemical state of the atoms.



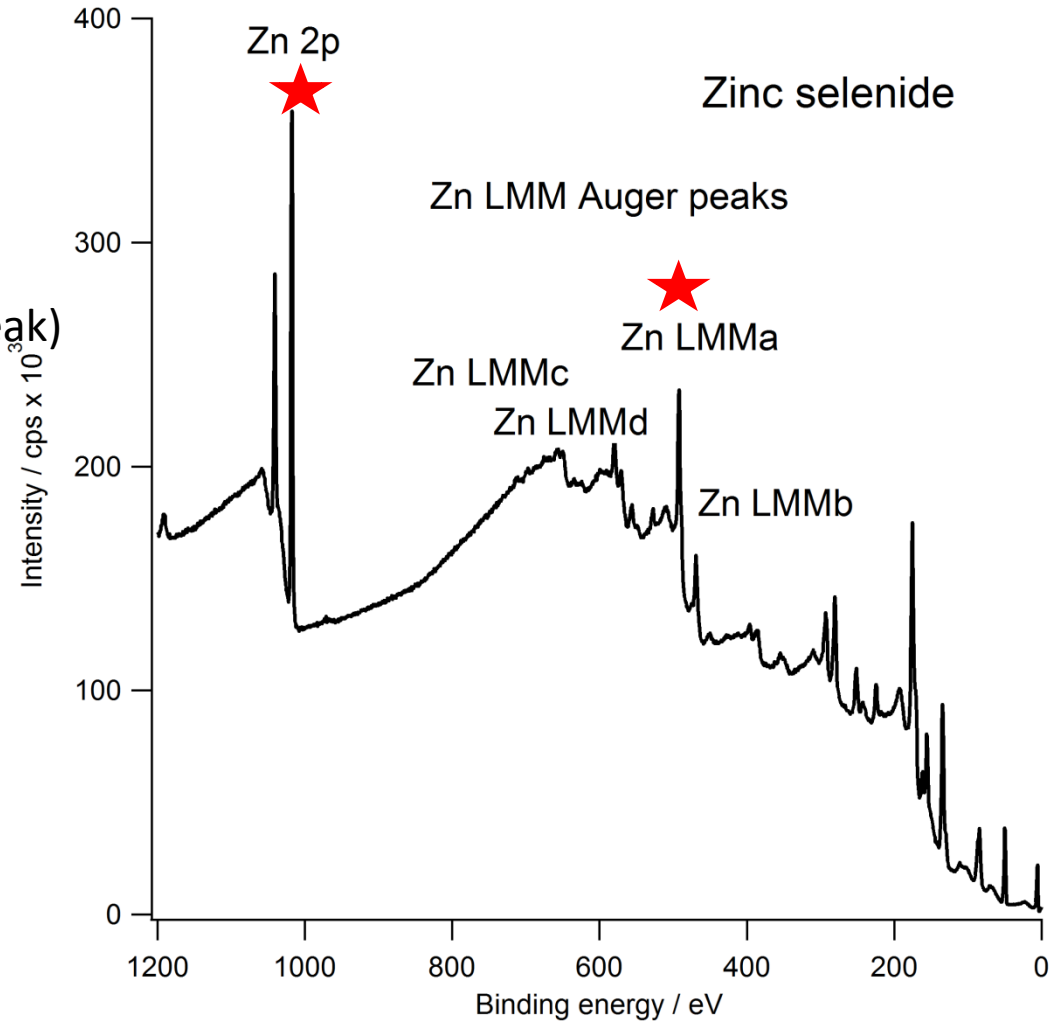
Auger peaks and the (modified) Auger parameter

The 'modified' Auger parameter is Defined as

α' = KE (Auger) + BE (Photoelectron peak)

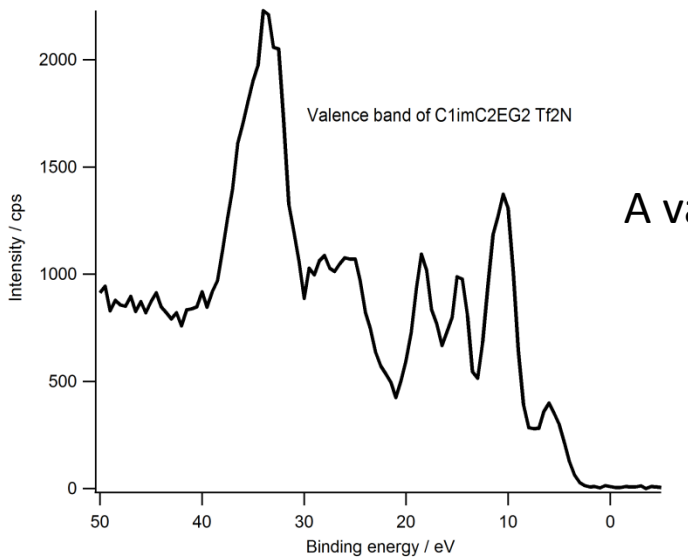
Note 1: The choice of the largest or best defined Auger peak is relatively arbitrary.

Note 2: Auger electron energy is independent of the X-ray energy, so if a different X-ray source is used the peak appears to move to a different apparent binding energy. BUT the Auger parameter stays the same!



The valence band

The outer electrons in the atoms in a material will all have very low binding energies. (Typically B.E ~ 35 – 0 eV). These electrons come from orbitals involved in the bonding of the atoms and the peaks are often complex and overlap. Some valence band 'shapes' are used to recognise similar polymers where the photoelectron peaks are very similar.



A valence band using X-rays 1486.6 eV

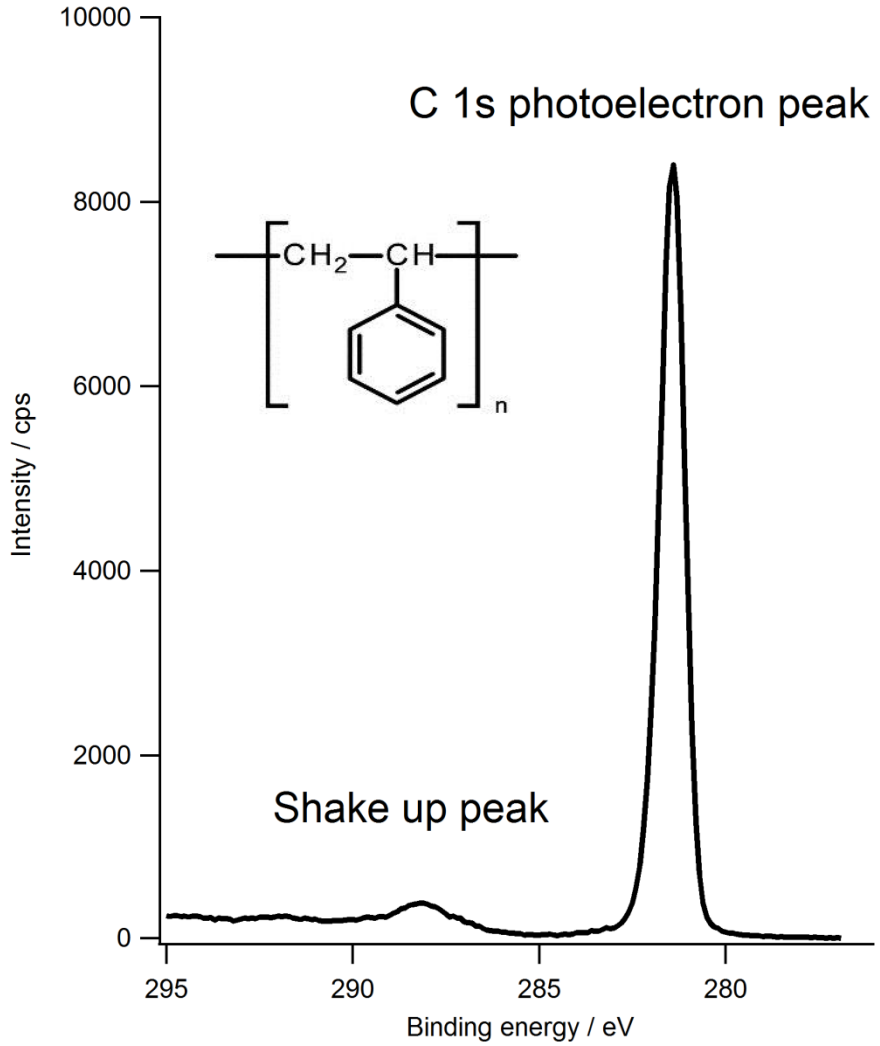
The peaks are also of low intensity since the photo-ionization cross section when the BE is so small is fairly low for X-rays ~ 1500 eV. Because of this, it is useful to probe the valence band with U.V. at ~ 20 or 40 eV instead to increase the cross sections and surface sensitivity.

Shake up (and shake off) features

Shake-up occurs where the exiting photoelectron can excite a resonant bond such as a π orbital to a discrete higher energy state, π* , losing a small amount of energy in the process. This produces a loss structure which can be a second peak or set of peaks at apparently higher BE to the main photoelectron peak.

Shake-off is similar but the excitation is into the vacuum level continuum of energy states so the energy step is not discrete , therefore the loss structure is usually hidden within the scattered background.

Both processes occur, so if shake-up is observed shake-off should usually be assumed, usually one estimates a similar loss of intensity from the main peak for each.

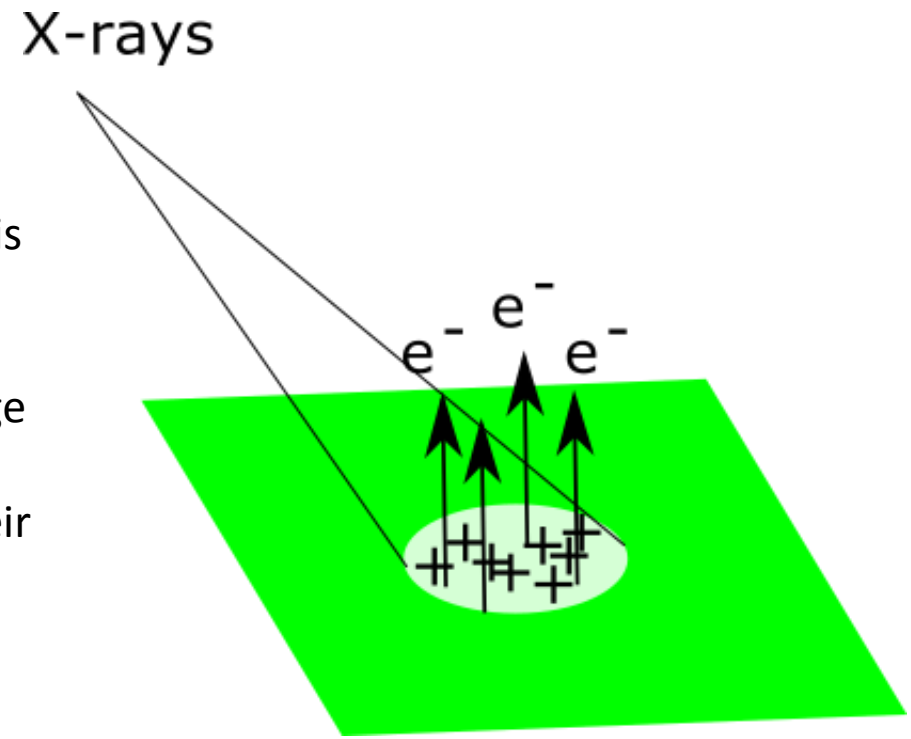


Charging shifts

Any surface irradiated with X-rays and producing photoelectrons will start to charge positively (because negatively charged electrons are leaving the surface).

An earthed metal sample will compensate this charge away from the conduction band electrons. A non-conductor or an isolated sample will not do this and the positive charge on the surface will start to attract back the photoelectrons. This leads to a change in their kinetic energy, which appears as an apparent increase in binding energy…….

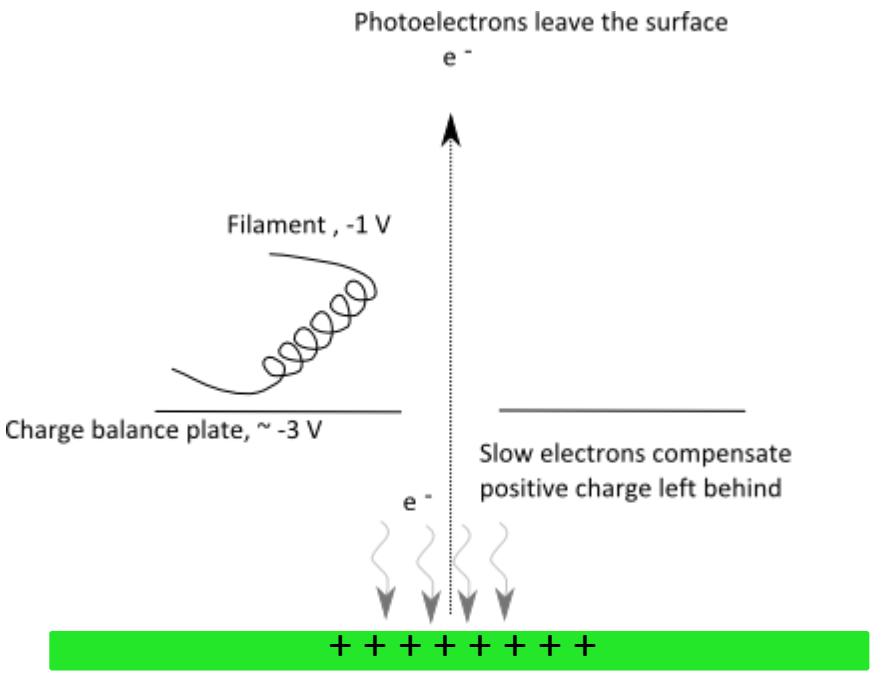
The peaks shift up the energy scale.



Charging shifts – charge compensation

Charge compensation with a charge neutralizer filament or electron gun is a physical method of removing the build up of charge at the sample surface. Different manufacturers use different methods, but all involve balancing the charge at the irradiated sample area using a flux of slow electrons or electrons and ions.

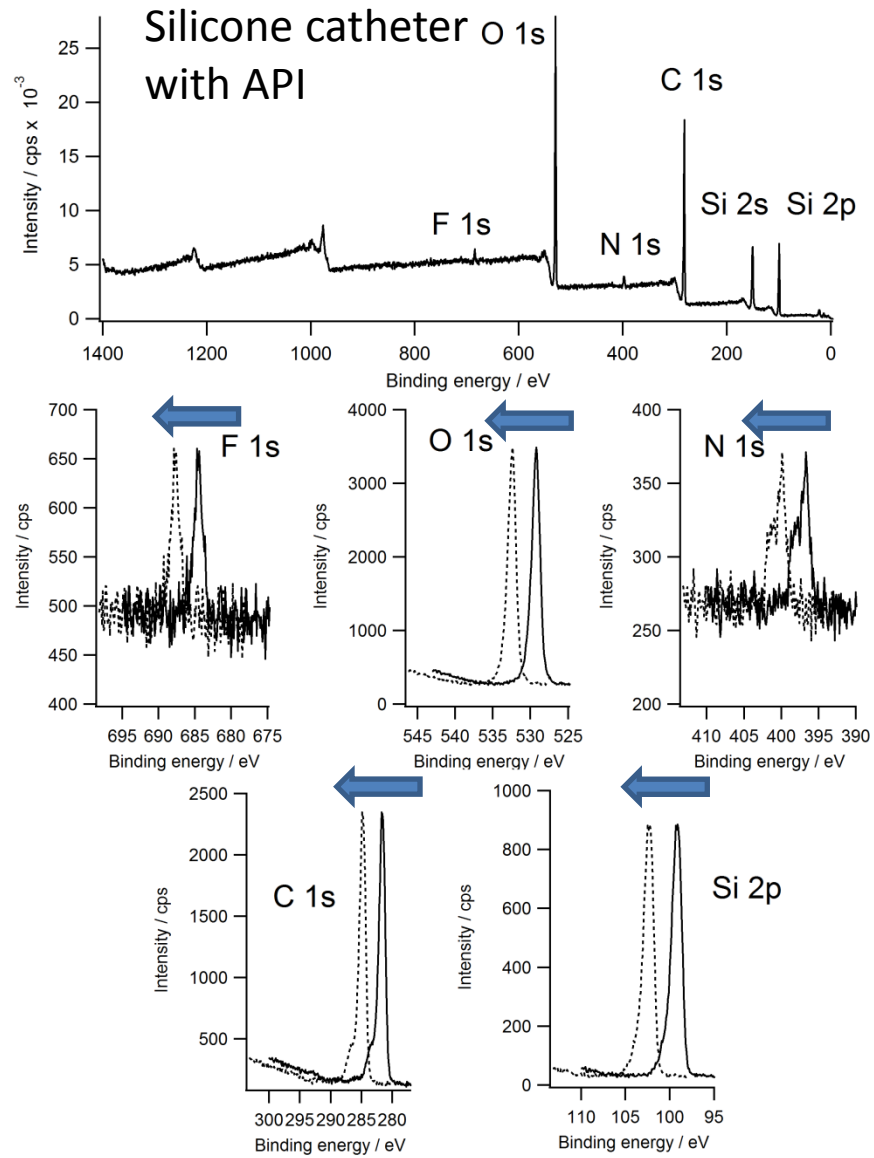
In some systems, charge neutralization requires a small bias voltage to be applied, the photoelectrons have higher kinetic energy and, therefore, lower apparent binding energy. (~ 2.5 eV) All peaks shift the same amount and this can be 'charge corrected' at the processing stage.



Charging shifts – charge correction

Charge correction is a data processing step applied after the spectra have been acquired to try and 'realign' the spectra from a charging sample to the fermi level. In practice it is simplest to align the spectra from one area of the sample to a 'known' reference peak.

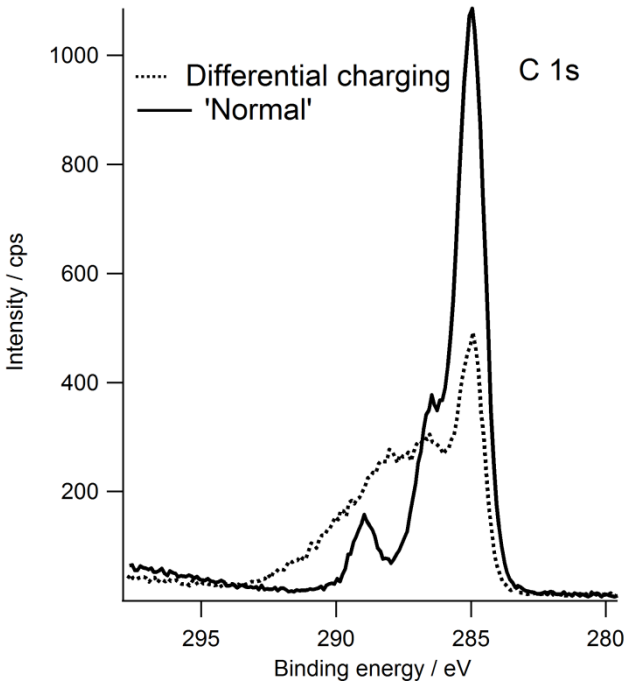
Commonly C 1s at 285 eV or 284.7 eV are used, but any suitable internal reference peak can be chosen.



Relative charging shifts

Differential charging of powders, fibres and other complex topography. Sometimes it is possible to reduce this by adjustment of the charge neutralization system.

Differential charging of layers
e.g. Aluminium oxide on Al metal
This can be remedied by isolating the sample so the layers all charge to the same potential

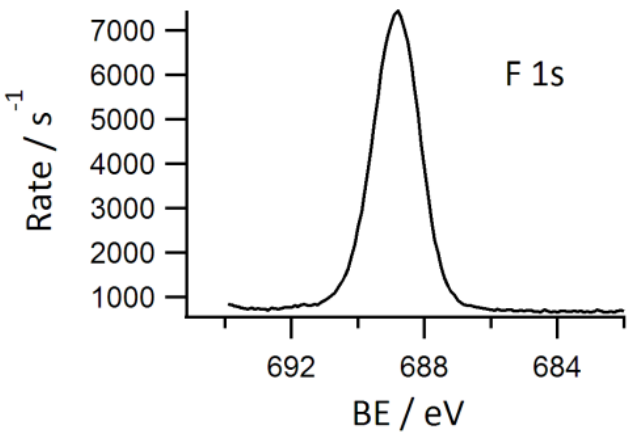


C 1s spectrum from fibre samples exhibiting differential charging (note that these spectra have been charge corrected)

Note that these situations cannot be readily resolved at the data processing stage and need to be dealt with during the measurements by sample isolation and adjustment of the charge neutralizer, although recognising the problem is useful!

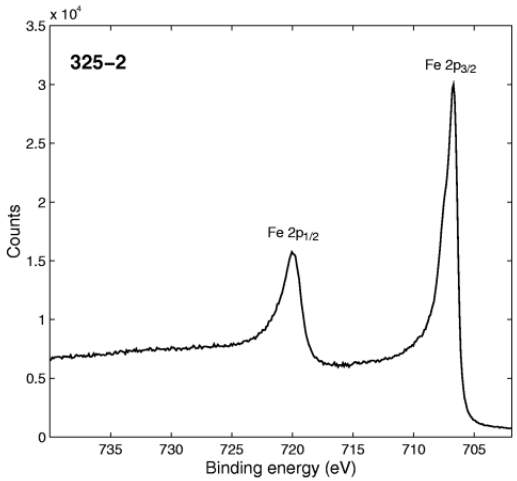
Peak asymmetry

Many photoelectron peaks are close to symmetrical in non-conducting and many semiconducting materials (e.g. polymers and metal oxides)



BUT: the metallic form of many elements will produce non-symmetrical peaks, with a 'tail' to the higher binding energy side.

This is due to the interaction of the photoelectron with the conducting electrons in the outer orbitals – close to the Fermi edge. The photoelectrons lose a small amount of energy to the valence band electrons and therefore have slightly lower K.E. The amount of asymmetry depends on the density of electron states near the Fermi edge.



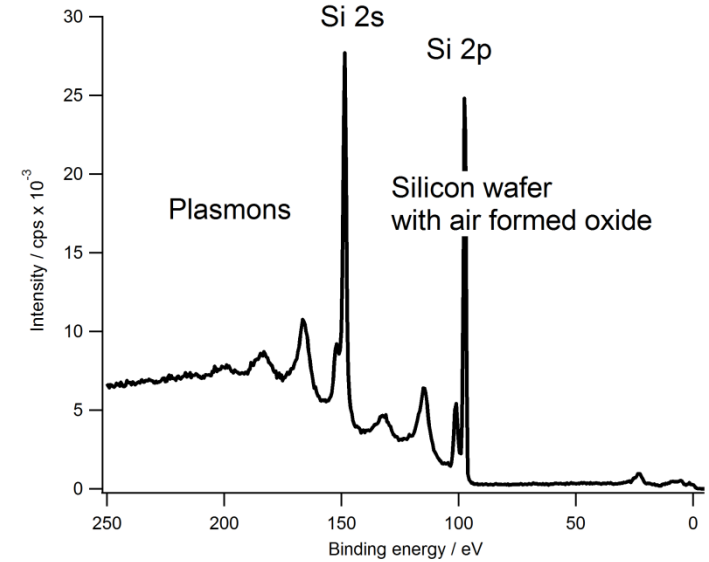
Fe 2p from the journal : Surface Science Spectra

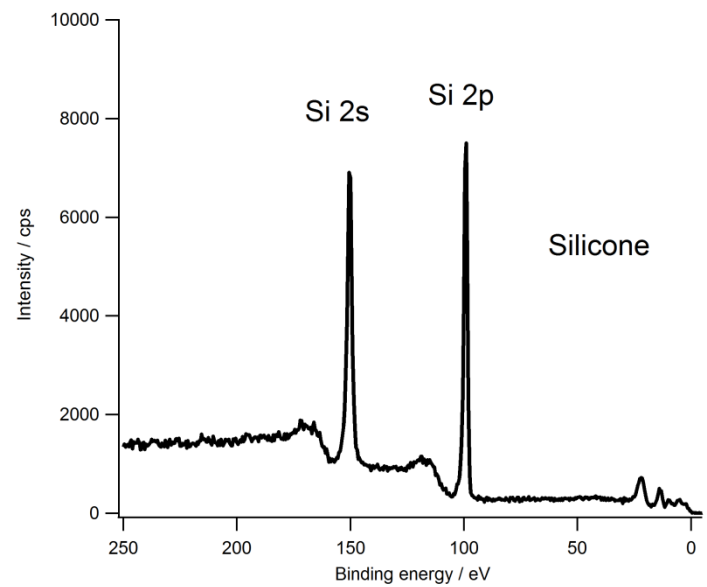
Surface and bulk plasmons

Some materials with well defined crystal structures can absorb energy from the photoelectrons into lattice vibrations. These are called 'plasmons' and can be 'bulk' or 'surface' (where the reordering of the atoms at the surface may have different vibration modes to the bulk material)

The loss structure can be seen to high binding energy side of the main peak, or sometimes is very close to it and is just observed as an asymmetry of the main peak.

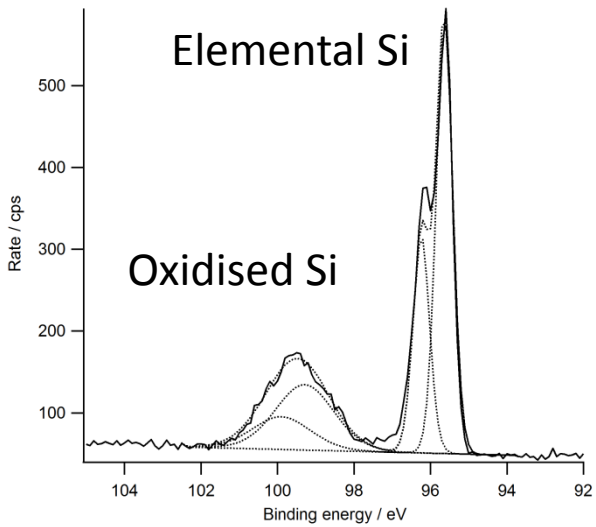
A classic example is silicon, which in pure form produces clear plasmon loss features and has a reduced photoelectron peak as a consequence. Whereas the silicon peaks from silicone /PDMS $(SiO(CH_3)_2)_n$ do not have these features.





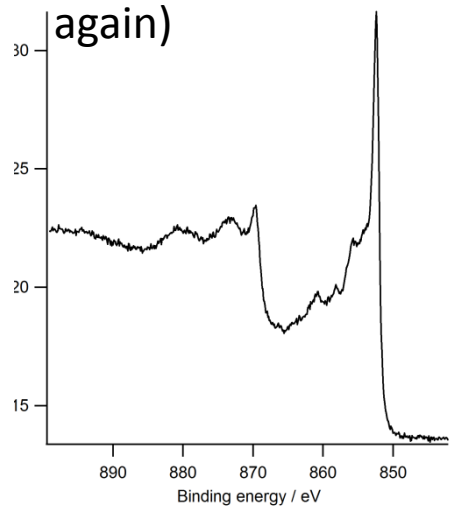
Examples of peaks with slightly more complexity

Doublets, with two chemical states



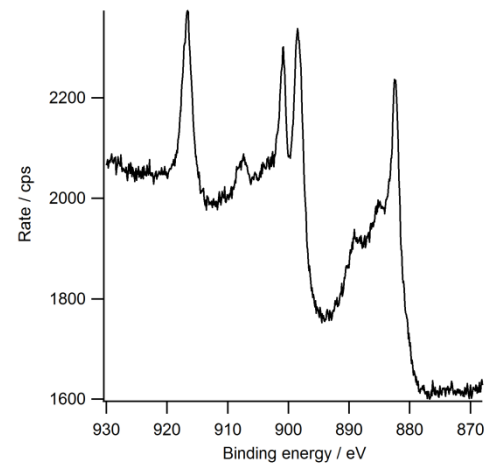
Si 2p doublets, on elemental
One is oxide, the distinct shift allow you to determine how much of each is present and work out an oxide thickness

Overlapping doublets (two chemical states again)



Ni 2p doublet with

One super-complex peak shape, but just one chemical state.

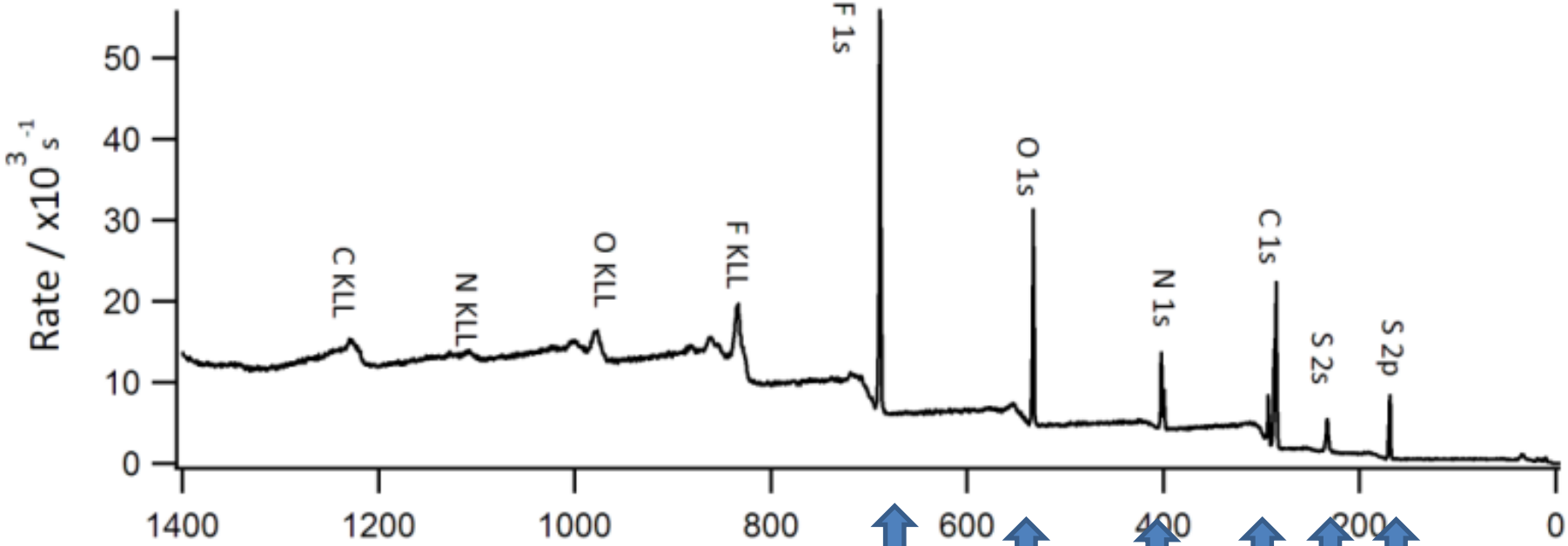


Ce 3d – a doublet with multiple satellites

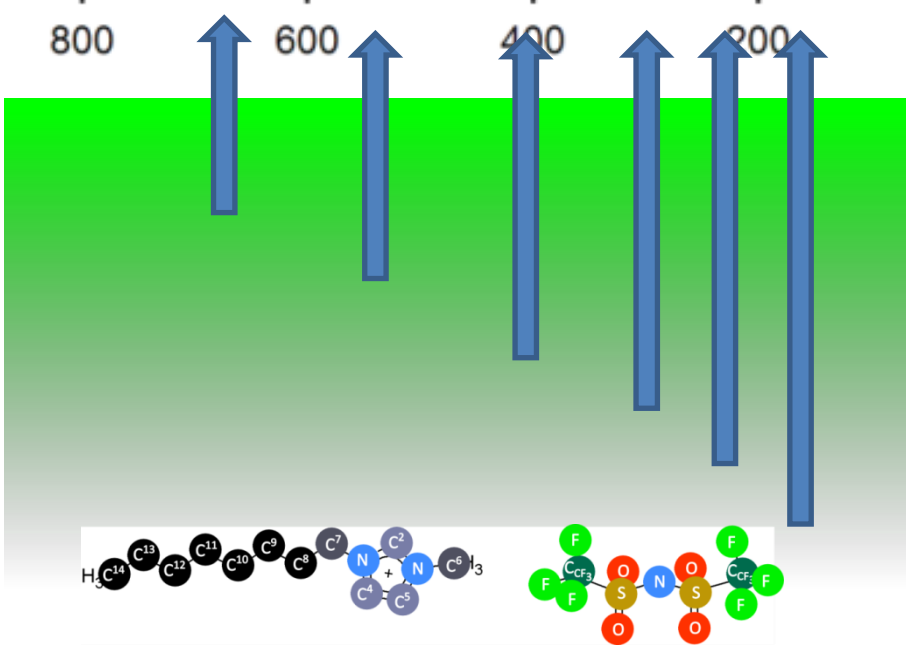
Apart from a quantification

– what can XPS do?

Kinetic energy – sampling depths



The photoelectron peaks arising along a wide scan spectrum are all probing different depths of the sample…….because the electron attenuation in the material depends on it's kinetic energy.



Kinetic energy: IMFP/AL and sampling depth

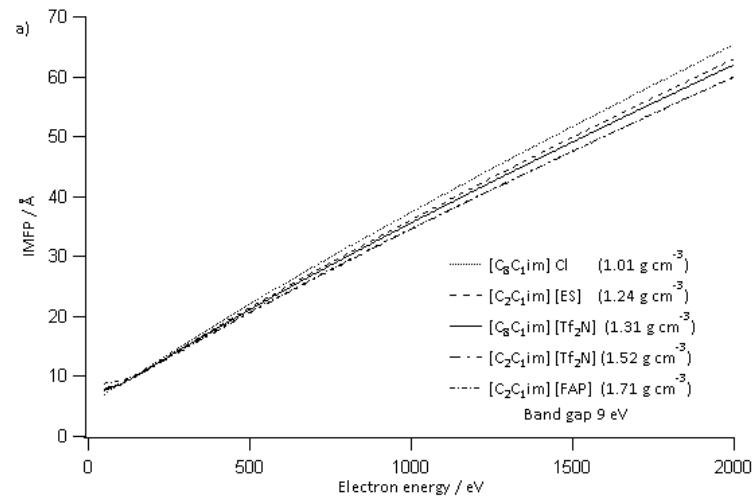
The inelastic mean free path (IMFP) of electrons in a material is the mean distance an electron of a given energy can travel through a material before suffering an inelastic collision.

For polymers the IMFP of electrons varies between 10 and 60 Å over the energy range 100 to 2000 eV. (1-6 nm). So only the electrons generated close to the surface will be able to travel out unperturbed and be detected.

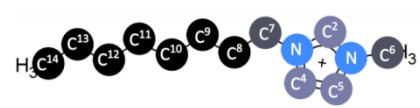
The effective attenuation length (E.A.L. or λ_{AL}) is related to this and is of the same order as the IMFP, they are often used interchangeably – but are not exactly the same!

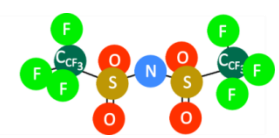
The information depth is

I.D. = 3 x λ_{AL}

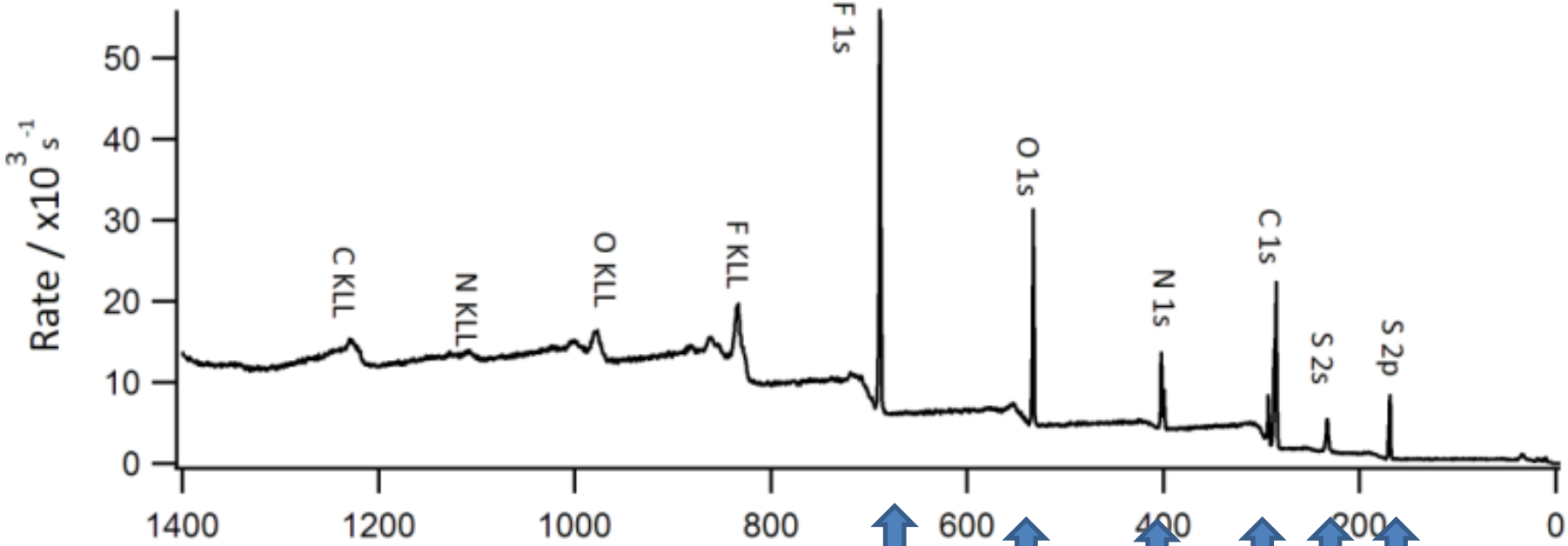


Graph of inelastic mean free path (IMFP) calculated from the TPP-2M predictive formula for organic compounds for electrons in the energy range 0 to 2000 eV a) for [C_8C_1im] [Tf_2N], [C_8C_1im] Cl, [C_2C_1im] [ES], [C_2C_1im] [Tf_2N], and [C_2C_1im] [FAP], Using a band gap of 9 eV.

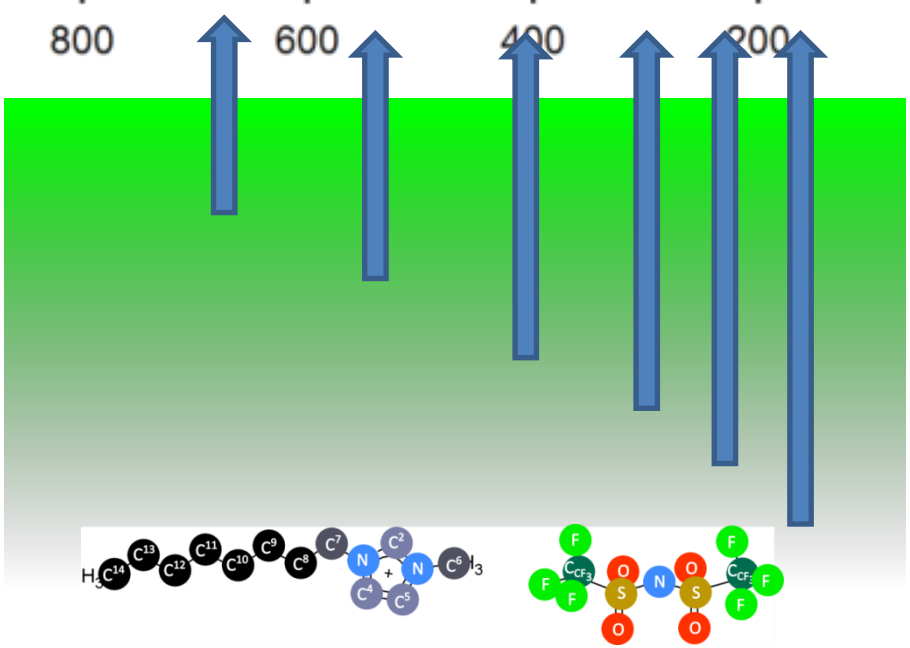




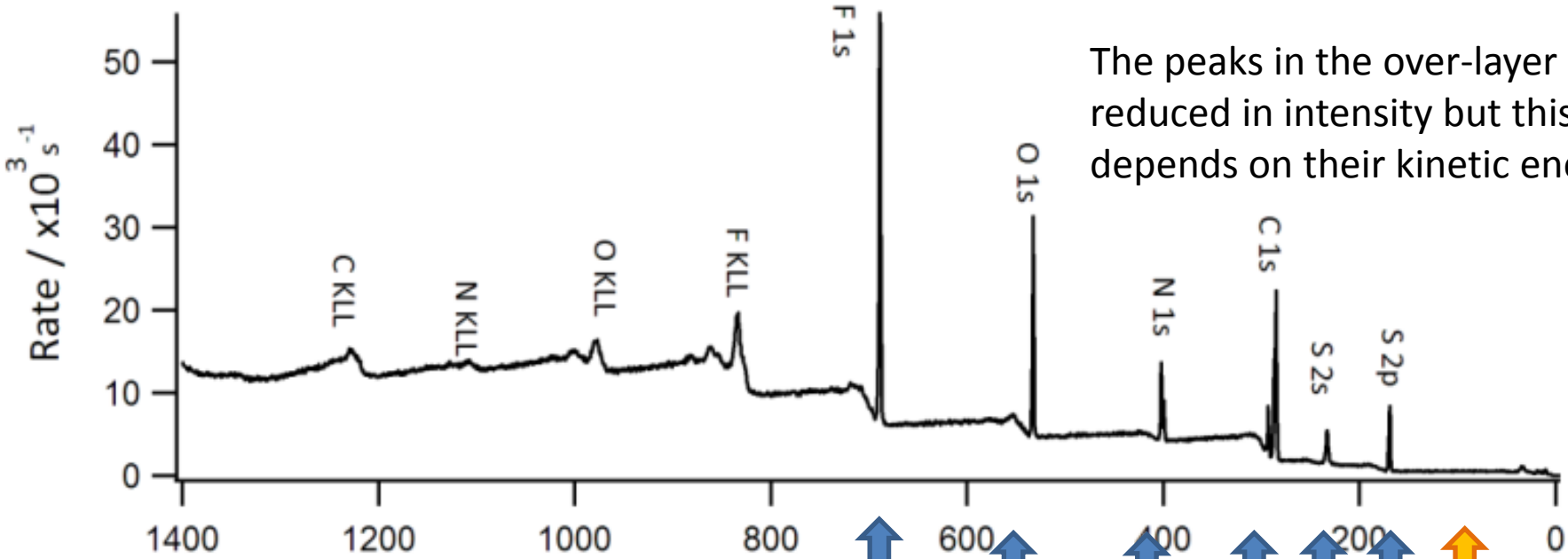
Kinetic energy – sampling depths



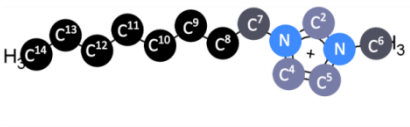
The photoelectron peaks arising along a wide scan spectrum are all probing different depths of the sample…….because the electron attenuation in the material depends on it's kinetic energy.

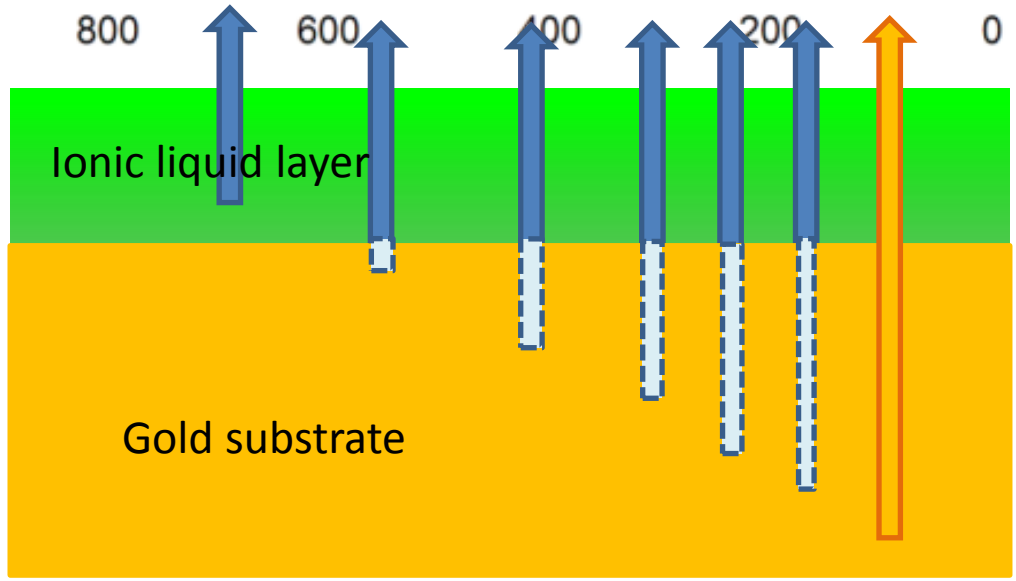


Over-layers and sample structure



The peaks in the over-layer are reduced in intensity but this depends on their kinetic energy!

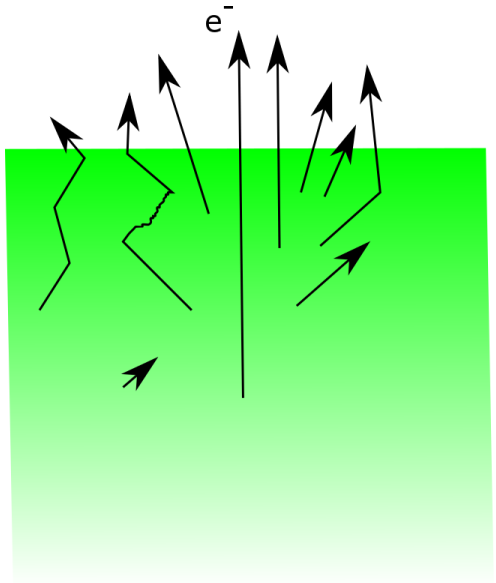


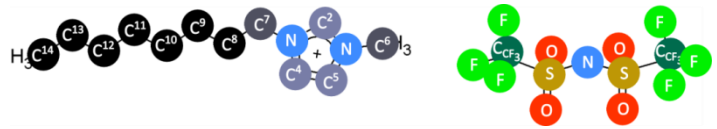


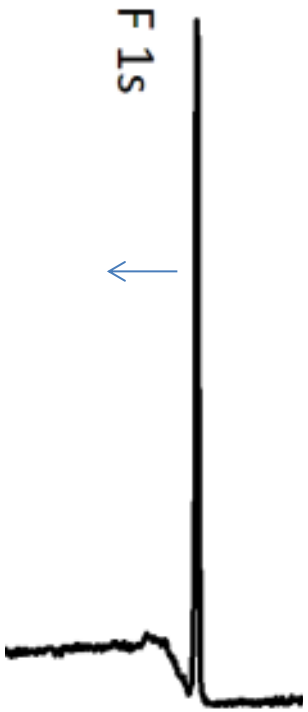
Missing signal from ionic liquid bulk

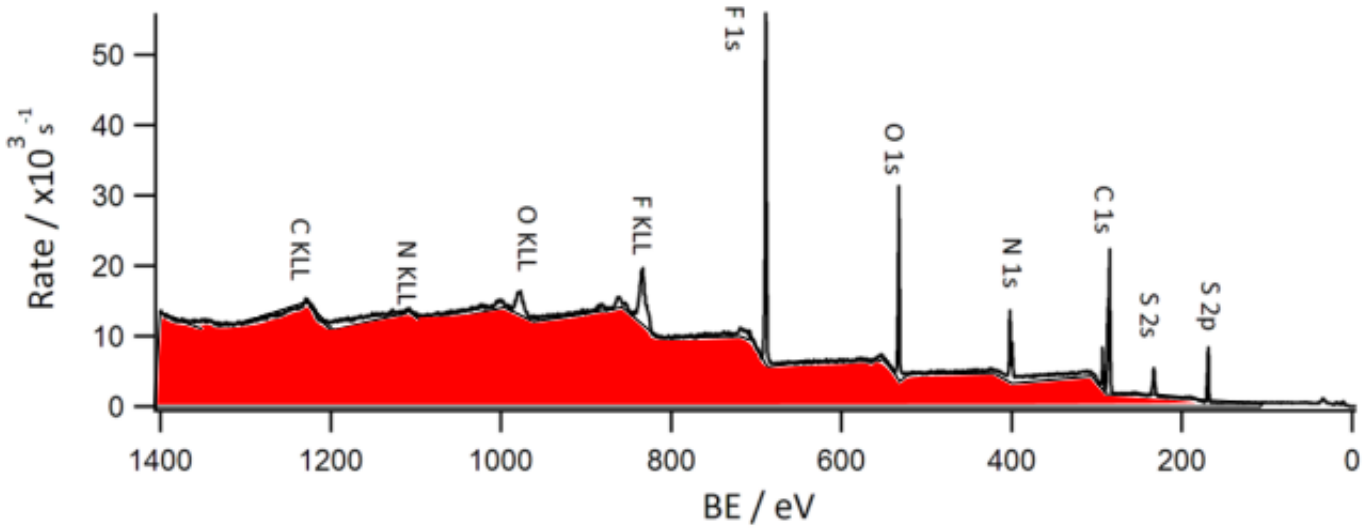
Scattered background

All photoelectron peaks have a ‘scattered background’ to the high binding energy side.
In reality this is photoelectrons from the main peak that have been slowed down by various collision processes in the material – so LOWER KINETIC ENERGY.







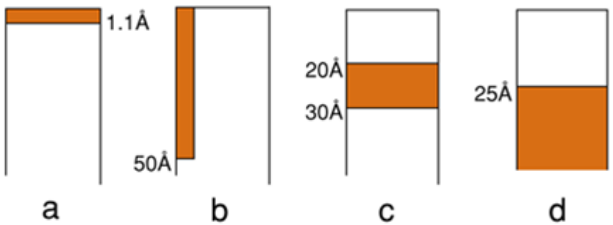


Using the scattered background

a) if the atom(s) emitting the photoelectrons are at the surface and do not have to travel through much material to leave the sample and be detected there will be no extra scattered electrons so the background level will not change much.

b) If the atom is deep in the sample under ~ 10nm of material many of the electrons that get out will have been scattered, so the peak will be smaller and the background larger.

CASAXPS or QUASES software can be used to interpret.



These surface morphologies all give the same XPS-peak intensity

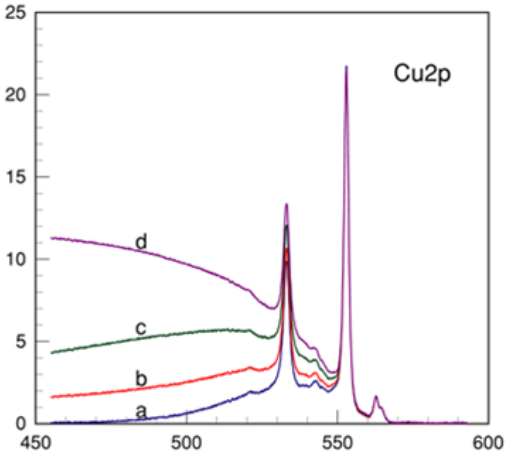
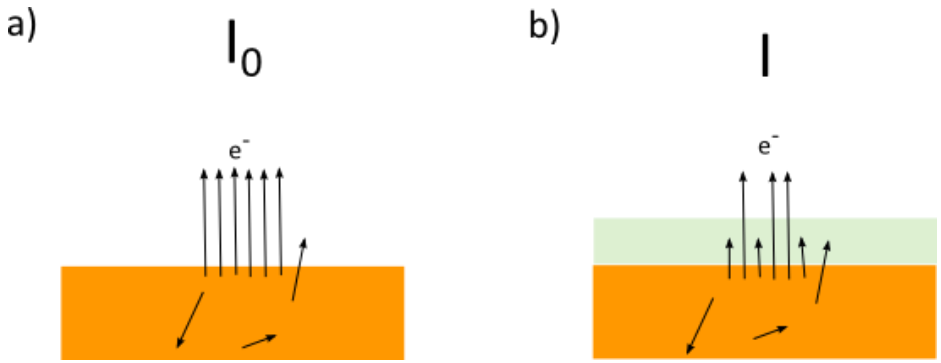
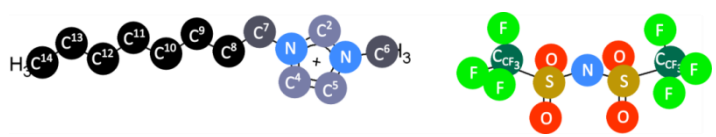


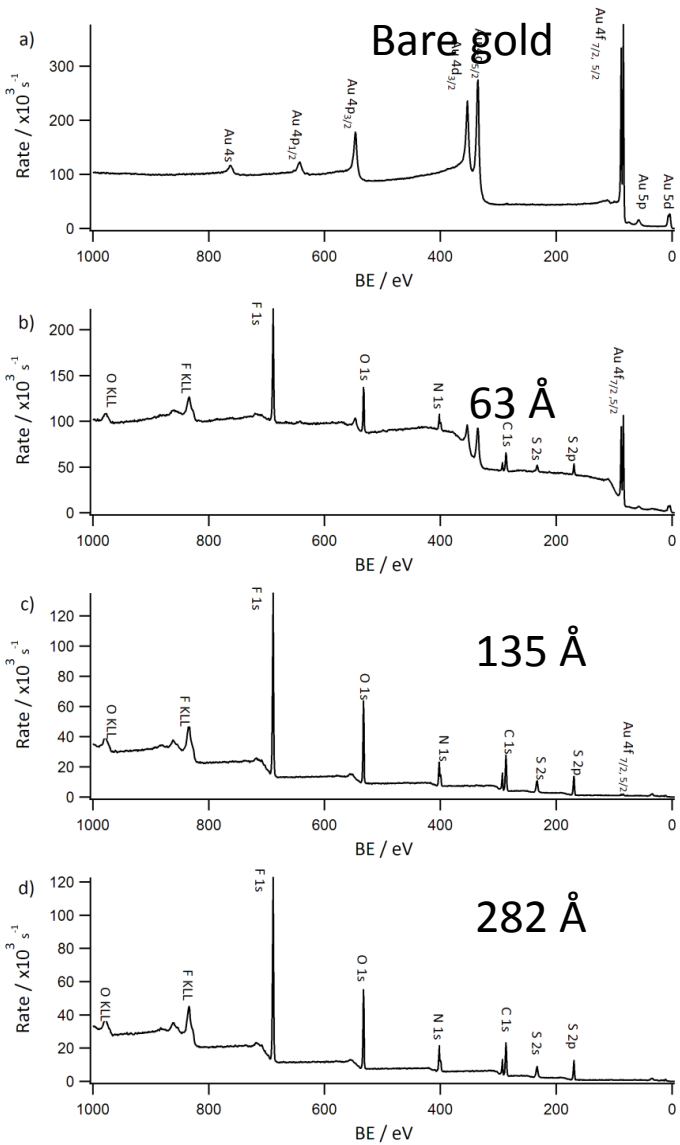
Figure from Sven Tougaard

Kinetic energy; over-layers and sample structure



$$I / I_o = \exp(-d/\lambda \cos\theta)$$

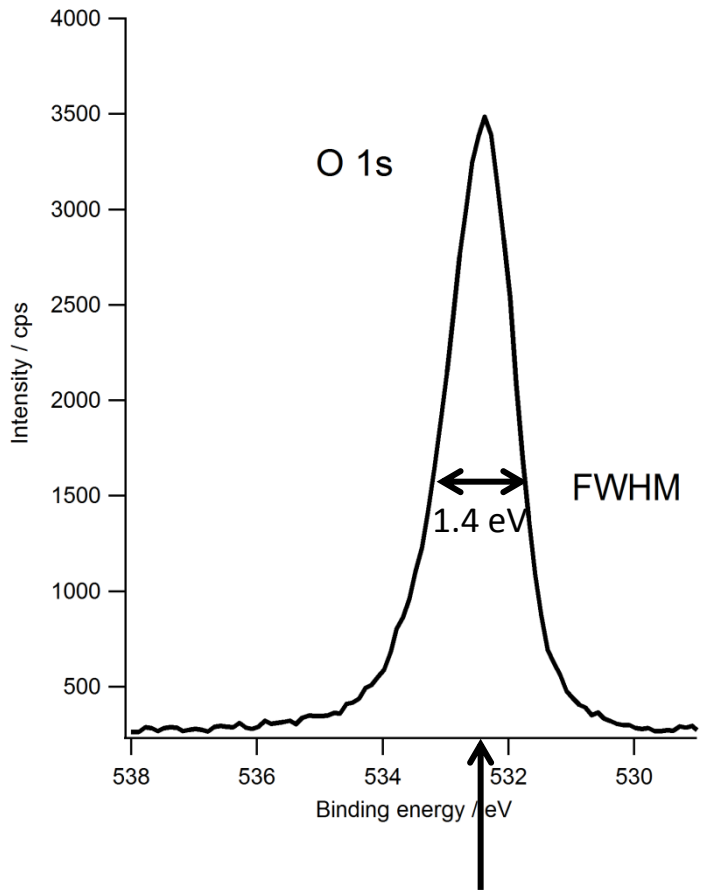




Some general points

Peak widths - What is FWHM?

The full width at half maximum height is a measure of how wide a peak is.



Peak binding energy – 532.2 eV

Peak widths – what contributes to the FWHM of a photoelectron peak

X-ray source width Mg ~ 0.7 eV, Al ~ 0.85 eV, mono-chromated Al ~ 0.16 eV.

Spectrometer/electron detection system resolution (Pass energy) Pass energies 5-50 eV would be considered ‘ high resolution’ and have FWHM of up to 0.7 eV a narrow photoelectron peak such as Ag 3d 5/2

The width of the photoelectron line itself is dominated by the lifetime of the excited state. (The longer lived the excited state before relaxation occurs the narrower the peak).

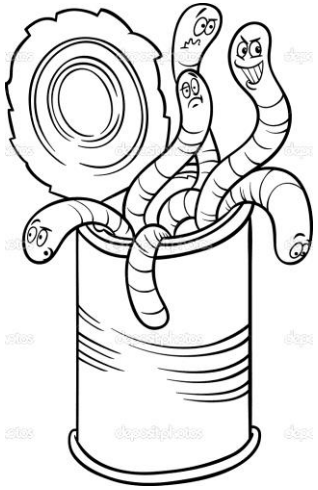
Oxidation states – If there is more than one very similar oxidation state a broader peak will be detected from the overlaid energies of these.

Vibration/plasmons/shake-up – loss of small amounts of energy can cause the peak to broaden asymmetrically to high BE side.

Sample charging – if it is not possible to compensate the charging at a sample surface differential charging may broaden the peak due to slowing down the exiting photoelectrons

The ultimate resolution of current mono-chromated instruments is approximately 0.25 eV This is based on the width of the fermi edge in a metal (often nickel or more practically gold) This is more commonly gauged by the peak width of a clean silver sample Ag 3d5/2 peak. ~ 0.45 eV.

Errors



It is important to assess your data for errors. Unfortunately there is no one size fits all approach, several different errors may be quoted for any given dataset. Commonly people quote a standard deviation for three measurements which gives a reasonable measure of sample repeatability. Generally it is good practice to review each measurement type on a case by case basis.

Accuracy of energy . If the spectrometer is calibrated in range using Ag/Cu/Au peaks **accuracy of ~ 0.1 eV or better should be achieved**. Precision (repeatability for a given instrument) may be better. Where a charge correction to a reference peak is used this accuracy will depend on your reference, so if you choose C 1s at 285 eV and it is really at 284.7 eV you will have poor **accuracy of +/- 0.3 eV but precision will still be better +/- 0.1 eV**. When peak fitting the energy position will depend mainly on the modelling!

Quantifications (at%) are based on peak areas, RSFs and TF of the instrument so accuracy will vary depending on how good these are. The peak area will vary slightly due to Poissionian counting statistics (noise) but this will only affect the precision of a measurement and can be estimated by measuring the same area multiple times.
RSFs for low cross section peaks in low abundance (e.g. B 1s) will bias any quantification due to the impact of noise on the total.
Accuracies for atomic % are typically +/- 10 at%, precision +/- 1 at% or better.
Of course, this all fails if the sample is not completely homogenous….

Some key equations

At% calculation

I/Io
and
Strohmeier. And generalised form

Thickogram (Cumpson)

Non-flat samples (Shard et al)

Nanoparticles (also Shard et al)

Thin films and monolayers

Other things you might observe in XP spectra

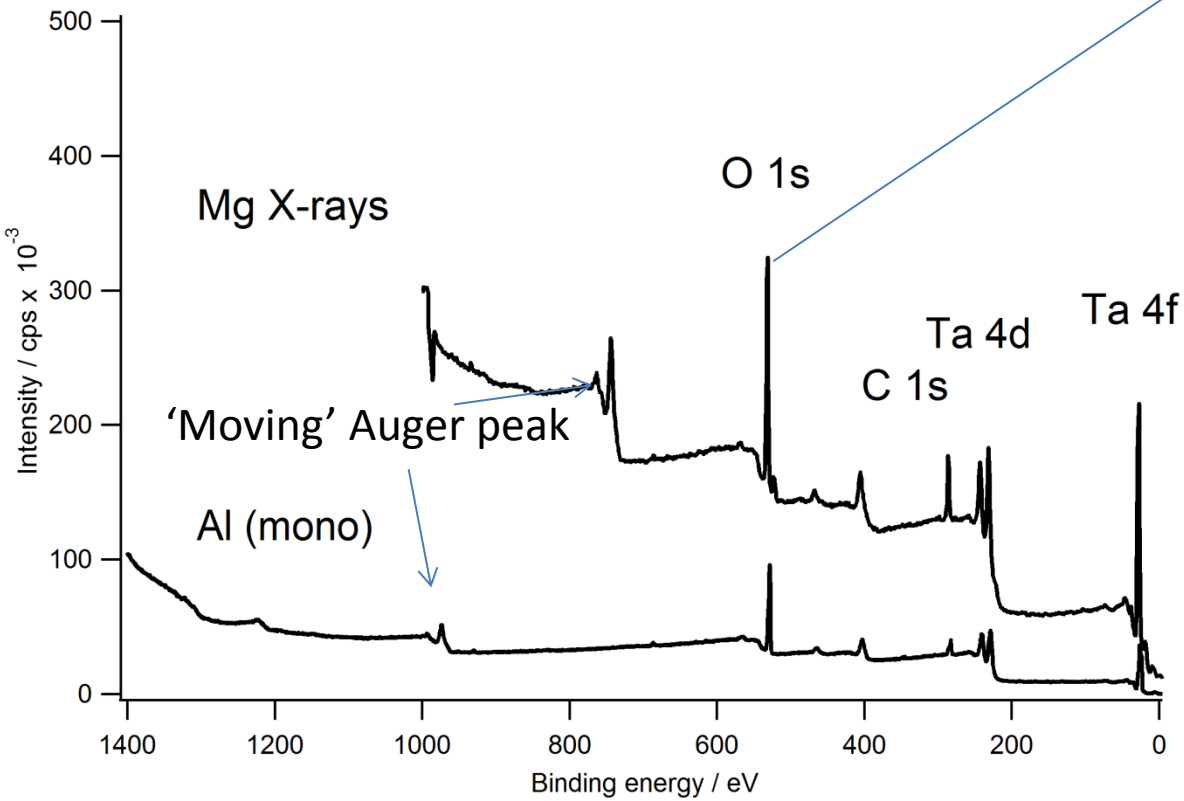
Other spectral features/ things to look out for

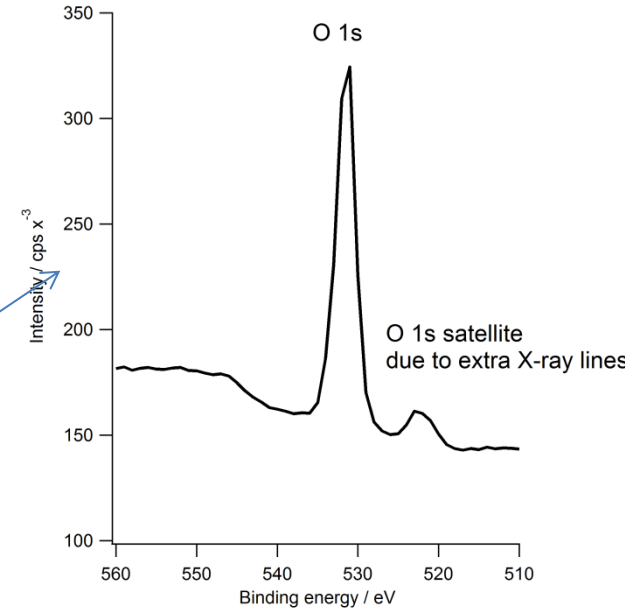
Contamination – **Always take a wide scan, and then look at your wide scans** for unusual or unexpected elemental peaks

Samples changing with time or under the X-ray beam (*e.g*. photo-reduction of some metal oxides) This tends to be more obvious if you observe the sample over long time periods and take high resolution spectra.

Other spectral features/ things to look out for

- Using different X-ray energies will change the K.E. of the photoelectron peaks produced, but not the Auger electron energy.
- Satellite peaks and 'ghosts' from non-monochromated sources because there is more than one energy of X-ray emitted.

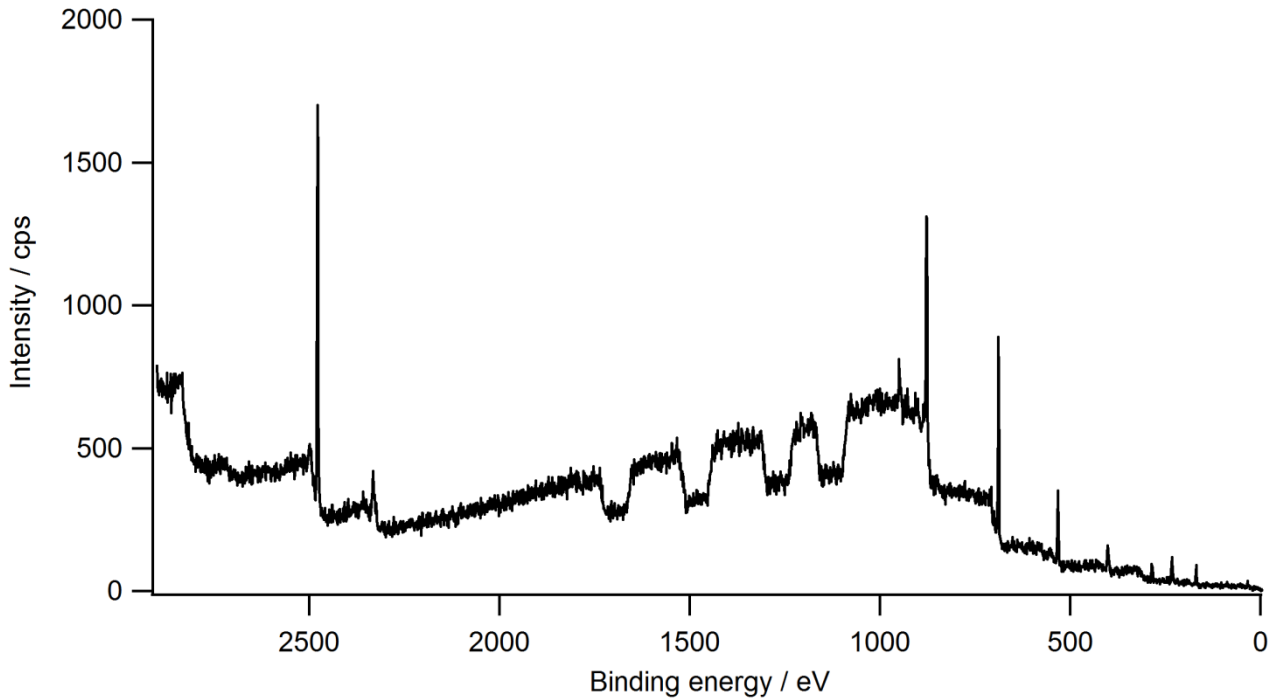




'Ghosts' or breakthrough lines are caused by extra X-rays from copper, where the anode face has worn away. (sorry no examples of this) Does not occur for monochromated sources

Other spectral features/ things to look out for

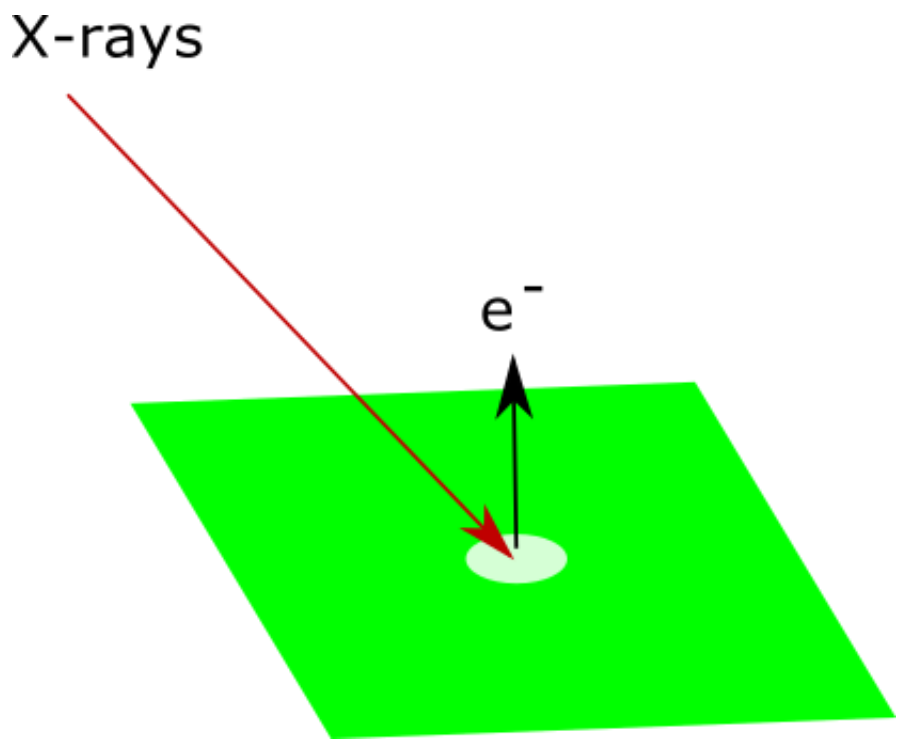
Spectrometer problems or X-ray source cutting out ….



Experiment types

Experiment types

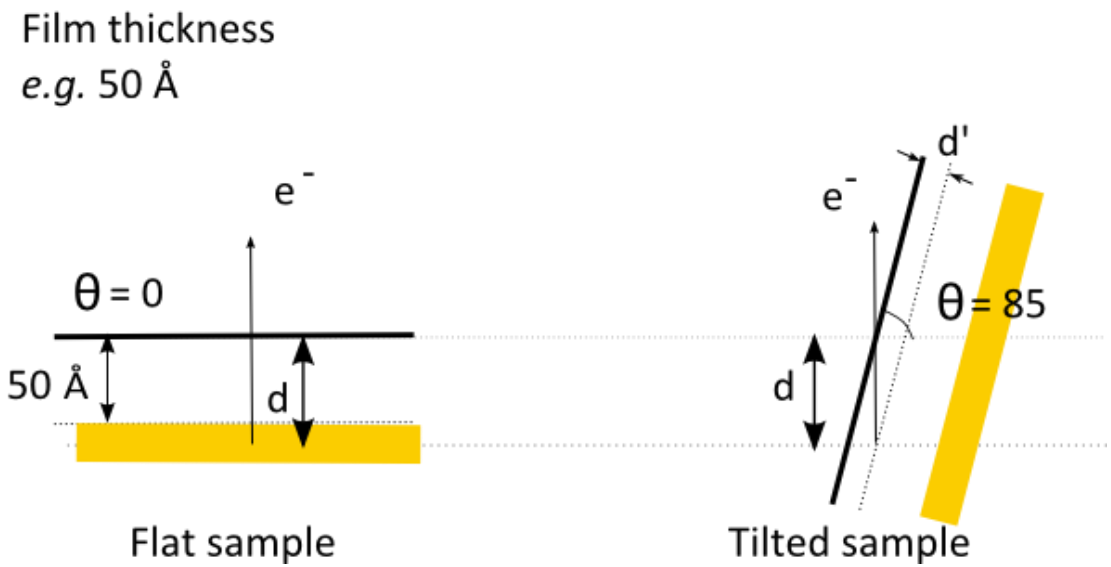
Simple spectroscopy



Experiment types

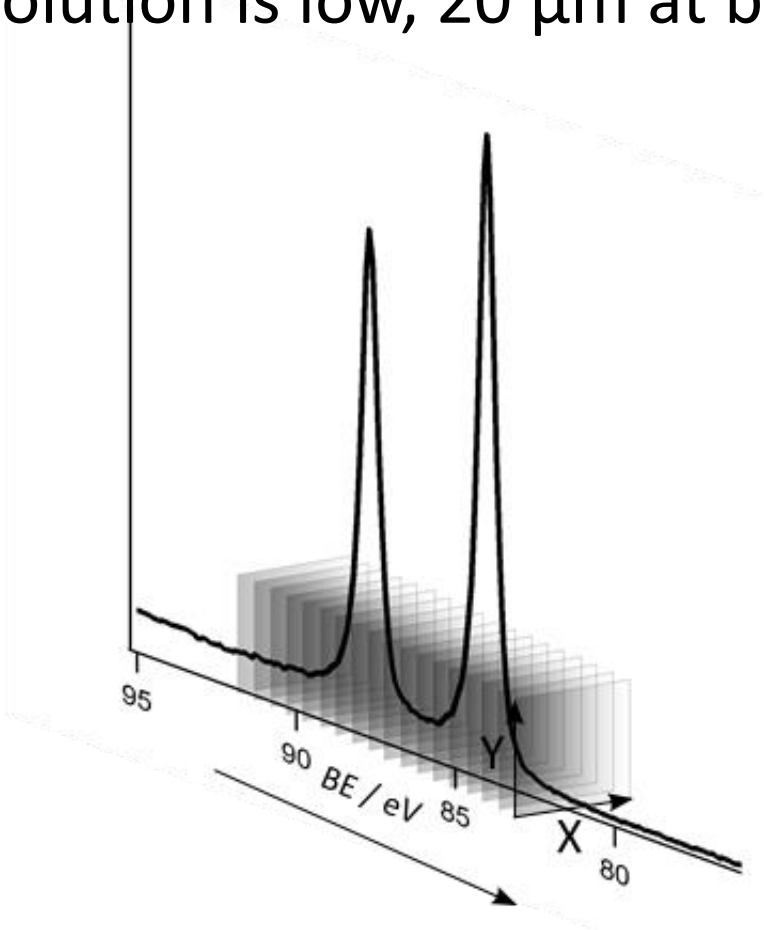
Angle resolved XPS

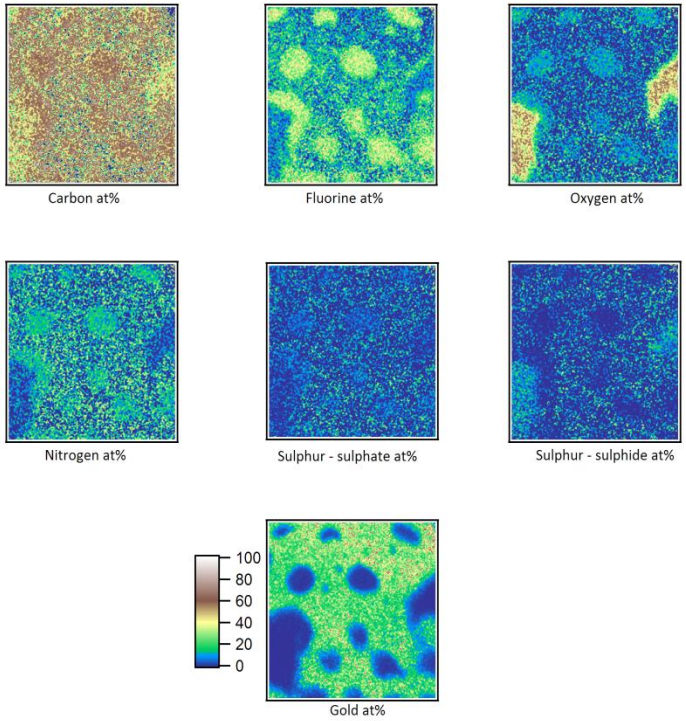
Tilting a sample relative to the electron detector will increase the surface sensitivity of the measurement.



Experiment types

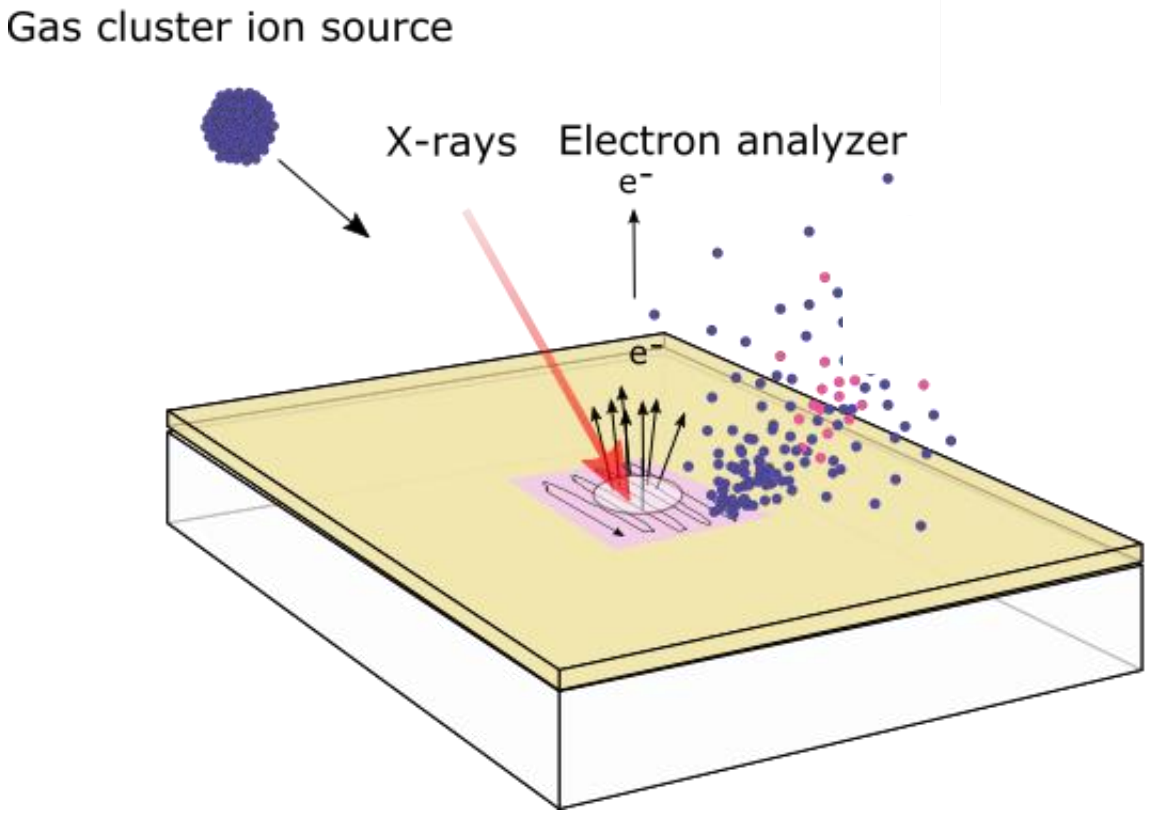
‘Spectroscopic imaging’ or ‘spectro-microscopy’, combined with PCA or other data processing methods. Lateral resolution is low, 20 µm at best.





Experiment types

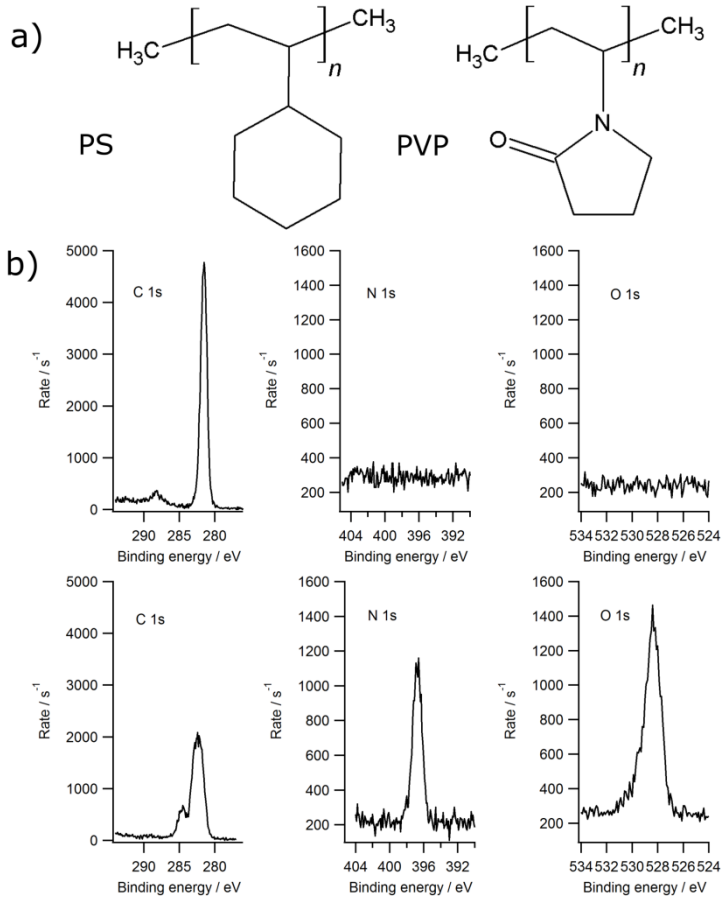
Depth profile

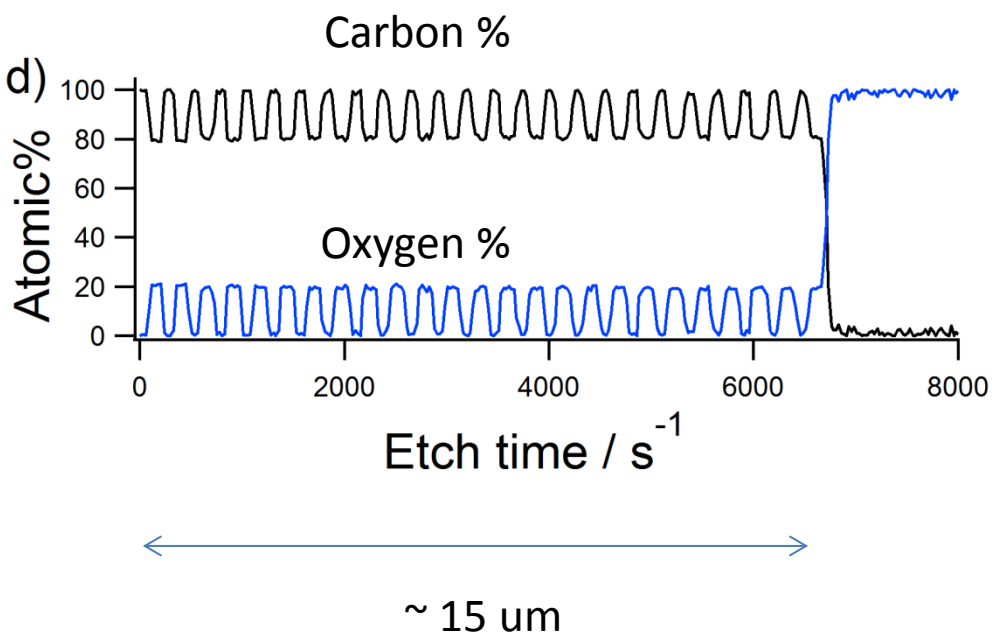


Experiment types

Depth profile

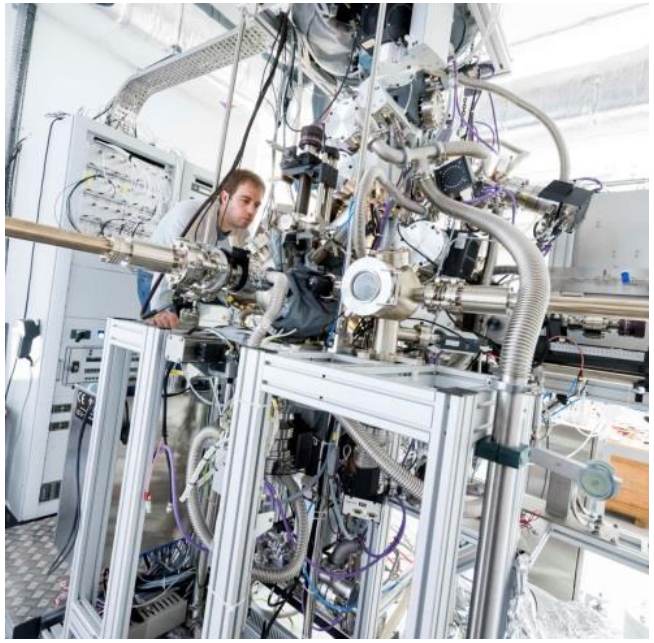
Experiment types
Depth profile

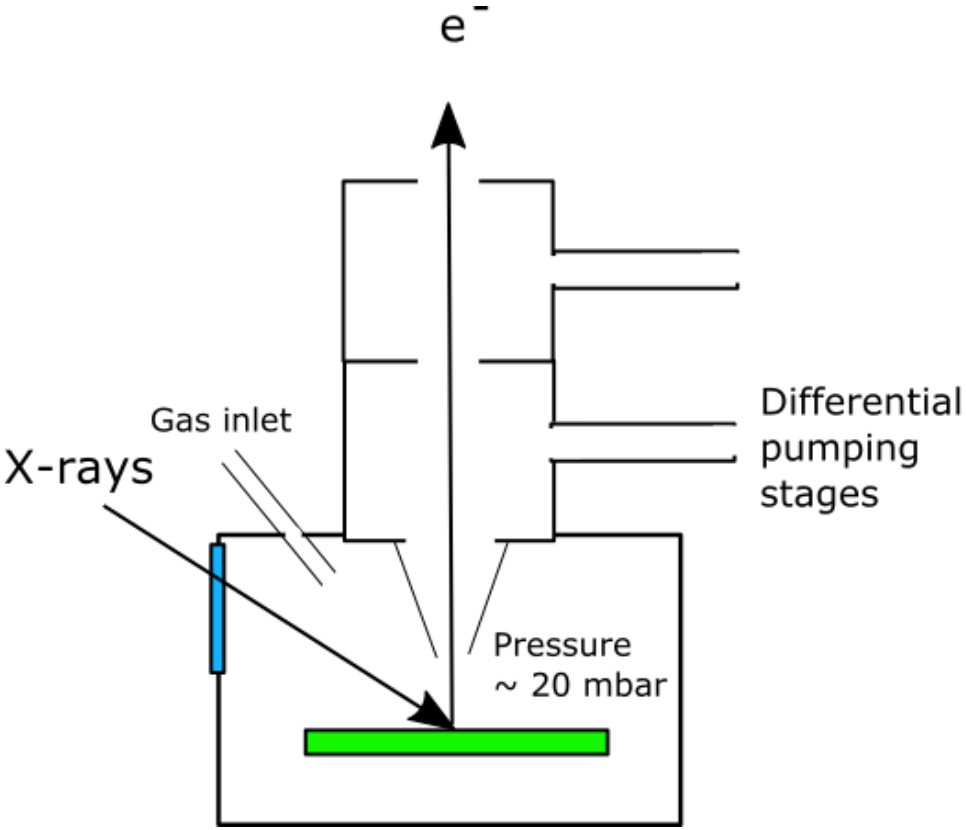




Experiment types

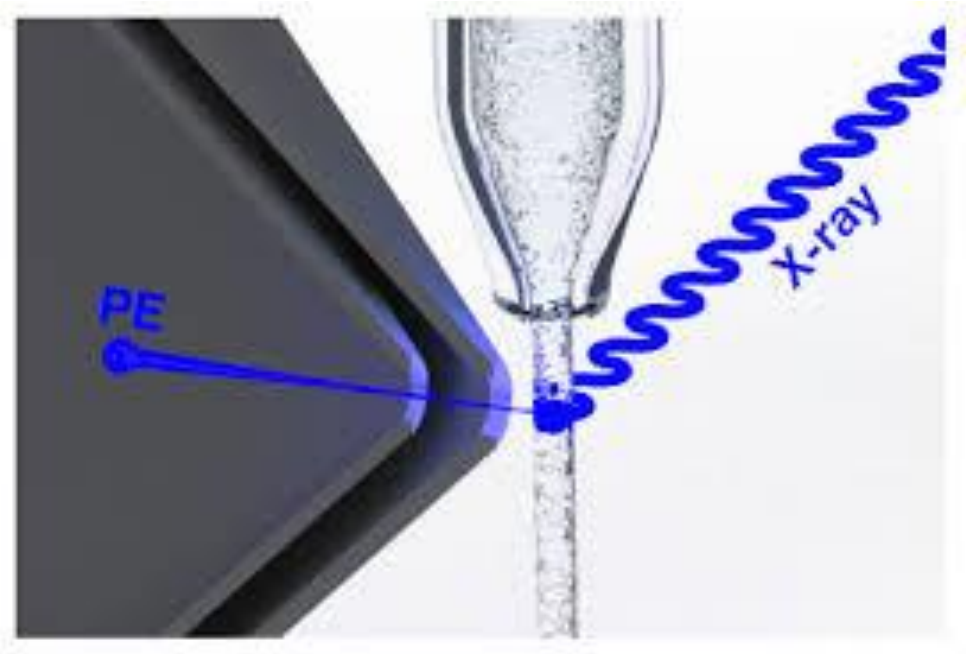
Near Ambient Pressure XPS (NAP-XPS) or High pressure XPS (HP-XPS)





Experiment types

Water micro-jet systems – at synchrotron sources only



e.g. Topics in Catalysis 2016, 59, 621-627.

Experiment types

Lab based UV sources – He lamp emitting He I and He II (< 50 eV) very good at exciting the valence band electrons.

New UV sources using lasers

10 – 300 eV

"Three-dimensional extreme ultraviolet emission from a droplet-based laser-produced plasma" Andrea Z. Giovannini and Reza S. Abhari, *Journal of Applied Physics*. dx.doi.org/10.1063/1.4815955

End of lecture:

additional slides for information below

Please complete the online course evaluation

To access the evaluation form visit:

https://nottingham.onlinesurveys.ac.uk/graduate-school-course-evaluation-survey

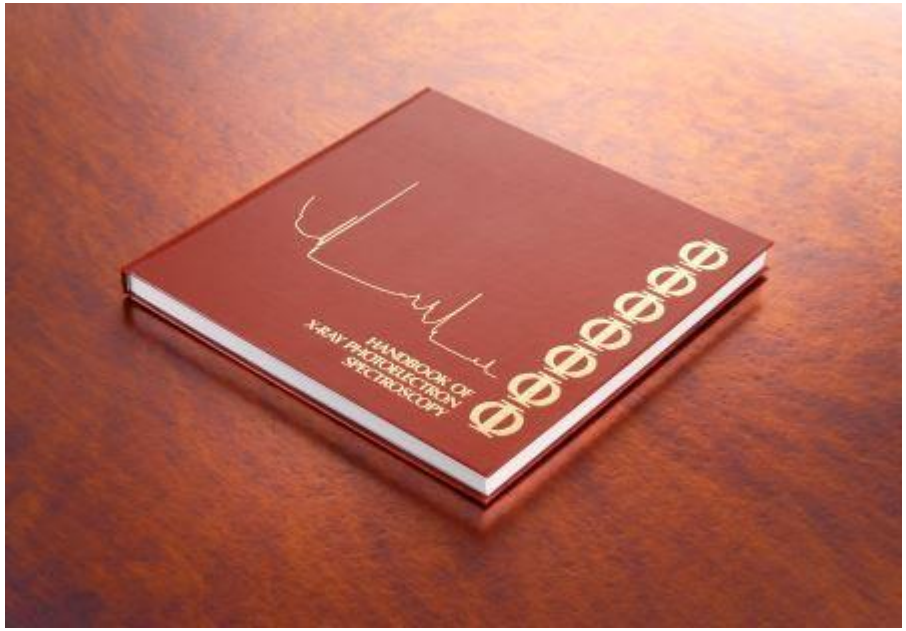
or using

http://tiny.cc/gradschooleval

Input the course date as 20/11/2019

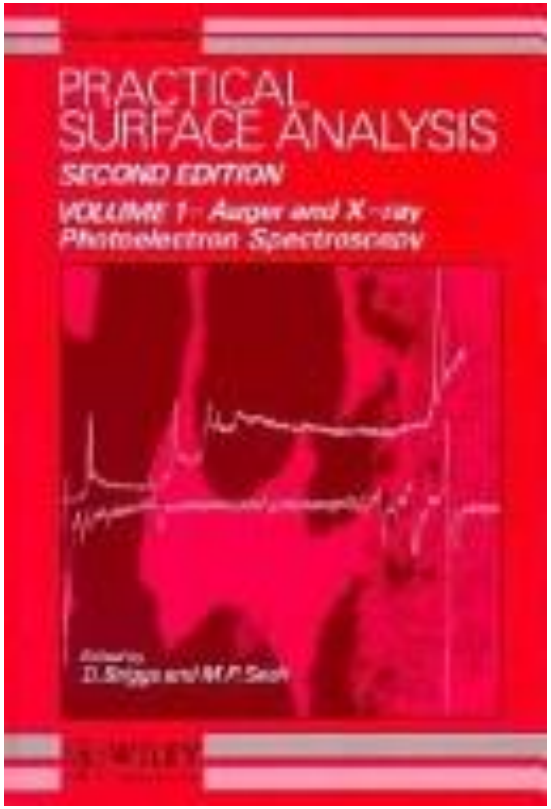
Input the course code as GSTXPS

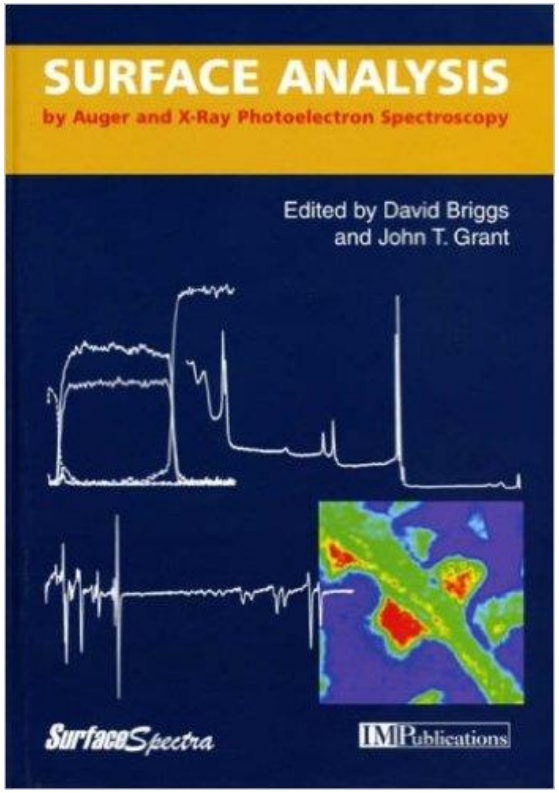
Resources



Handbook of X-ray Photoelectron Spectroscopy, 1995, John F Moulder et al, Ulvac Phi. (The Phi handbook)

Resources

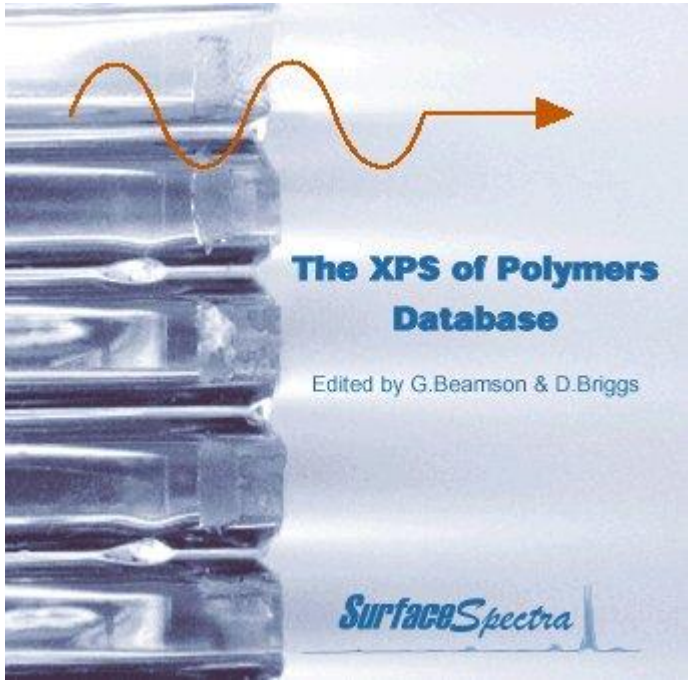




Practical Surface Analysis; Volume 1 - Auger and X-ray Photoelectron Spectroscopy, Briggs a
Seah, 2nd edn, Wiley, 1992.

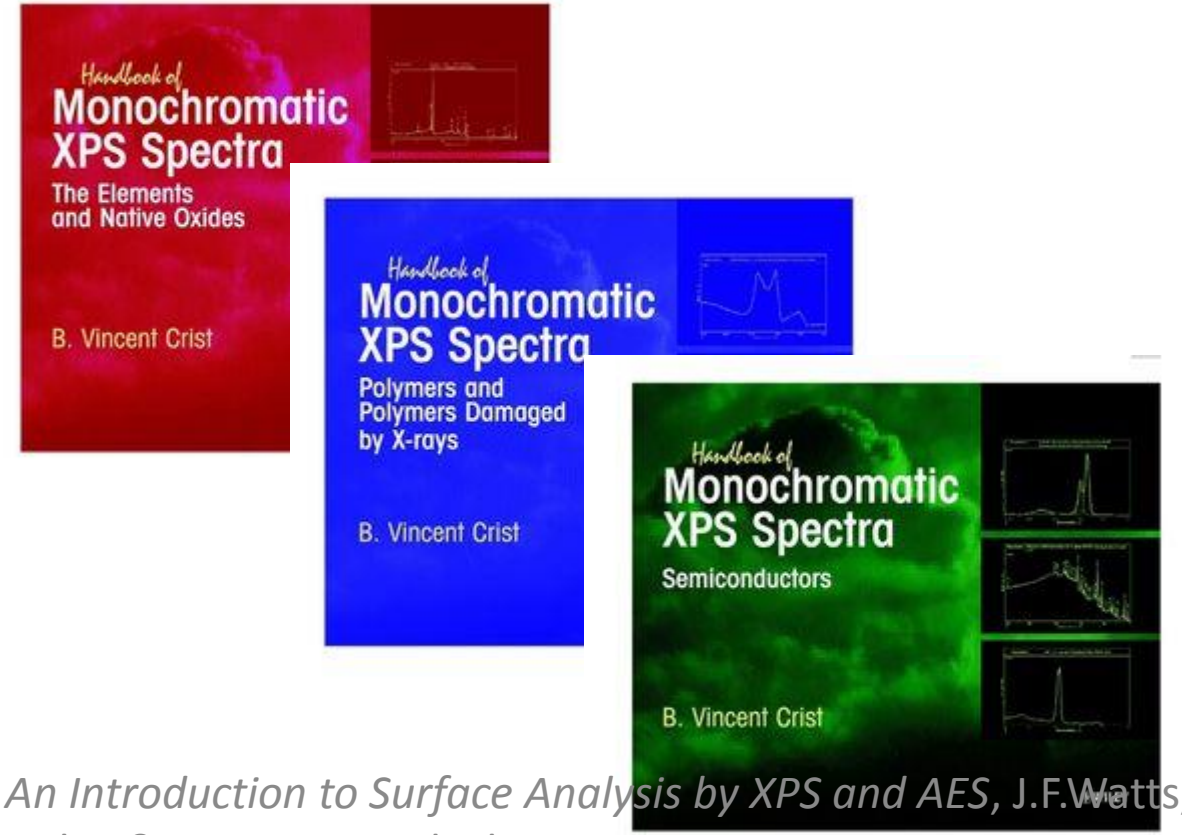
Surface analysis by Auger and X-ray Photoelectron Spectroscopy. Grant, J. T., & Briggs, D. (20
Edited Book, IM Publications.

Resources



The XPS of polymers database, ‘Polybook’ and appendices, Surface Spectra. Beamson and Briggs

Resources



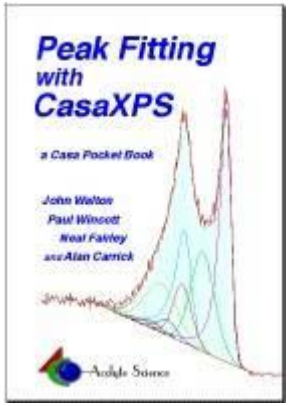
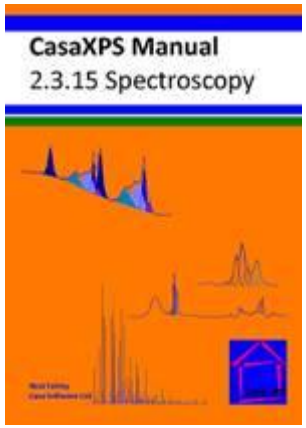
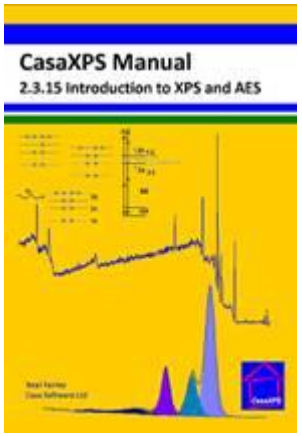
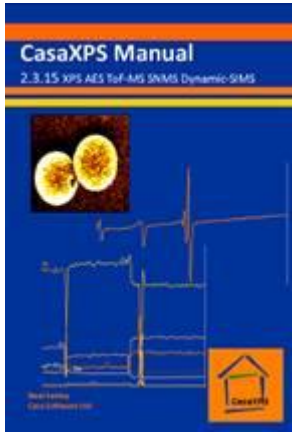
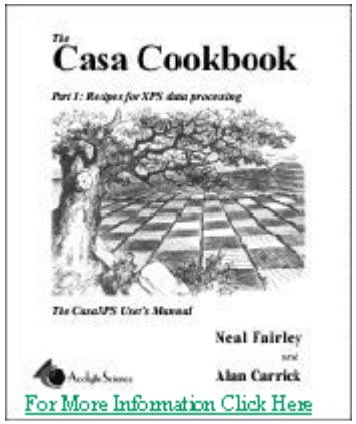
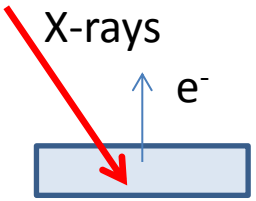
An Introduction to Surface Analysis by XPS and AES, J.F.Watts, J.Wolstenholme, published by Wiley & Sons, 2003, Chichester, UK, ISBN 978-0-470-84713-8

Surface Chemical Analysis — Vocabulary, ISO 18115 : 2001, International Organisation for Standardisation (ISO), TC/201, Switzerland, [1]

Resources - websites

CASAXPS.com & **YouTube CasaXPS channel**

LASURFACE

NIST XPS database

XPSfitting