

Topic Outline

IIIA. Signal Processing

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Terminology

signal	the measured value obtained as the result of an experiment
noise	random fluctuations in the magnitude of the signal value
spectrum	a collection of signals sorted sequentially as a function of an independent variable
channel number	the index number of one data pair (signal, variable value) in a spectrum
signal processing	manipulation of a signal at a given channel (to change its value)

Methodology

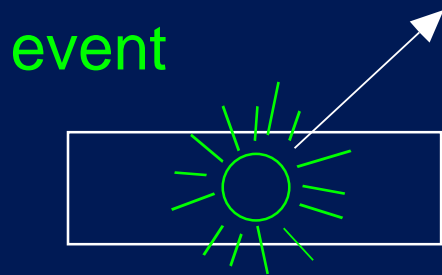
Signal processing can be done by the equipment before the signal is recorded (by computer or on a chart recorder) or by computer software after the (raw) signals have been stored. The latter method is preferred, however the former sometimes cannot be avoided.

Signal processing via software can be computer intensive!

Signal processing should be done with care!

Source

In spectroscopy, the source of a **signal** is an **event** that has occurred at the sample.



e^-

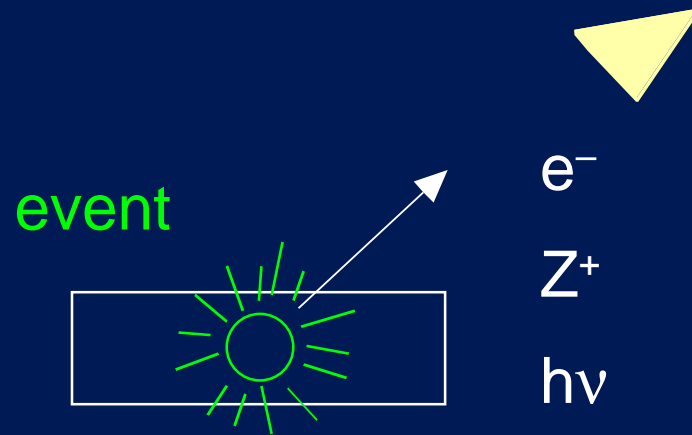
Z^+

$h\nu$

Typical signals in surface spectroscopies are electrons, ions, or photons (electromagnetic waves).

The signal is the number of the particles or waves at a given set of experimental conditions.

Detection



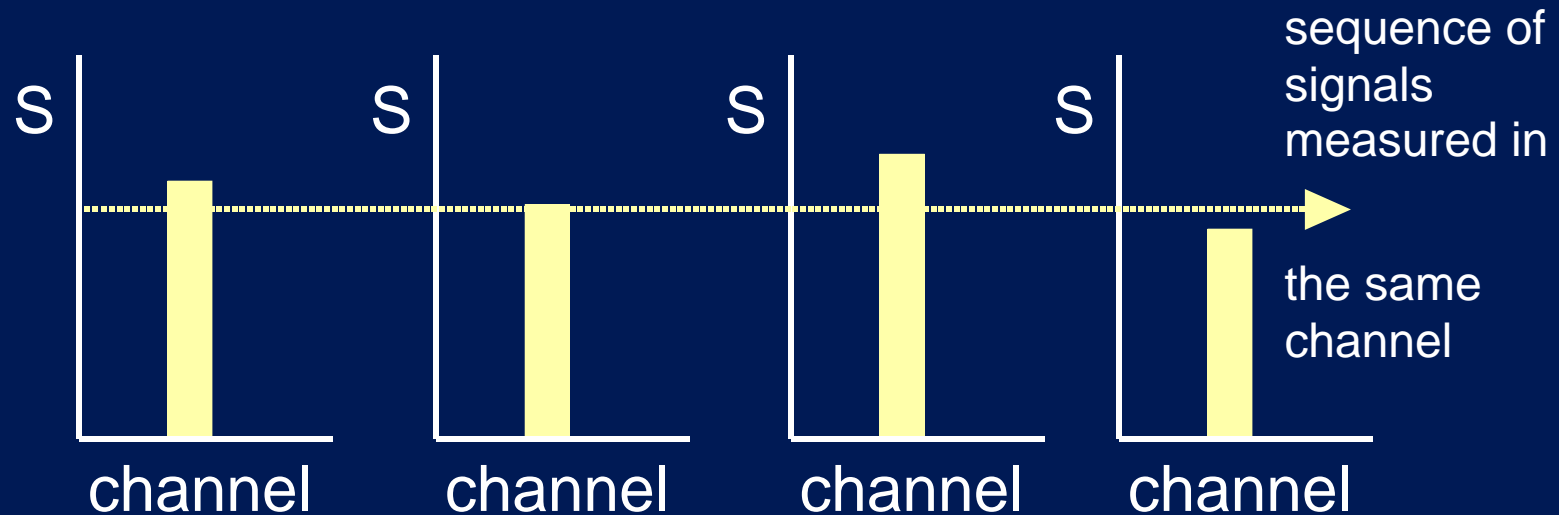
The detector is designed to count the signal that arrives in a given increment of time.

All else being constant, signal S (the number of counts detected) increases in direction proportion to the amount of time we spend counting, Δt .

$$S \propto \Delta t$$

Source

Noise is an example of **random error** in a signal. It is only defined by comparison between at least two independent measurements of signal measured when all else is constant.



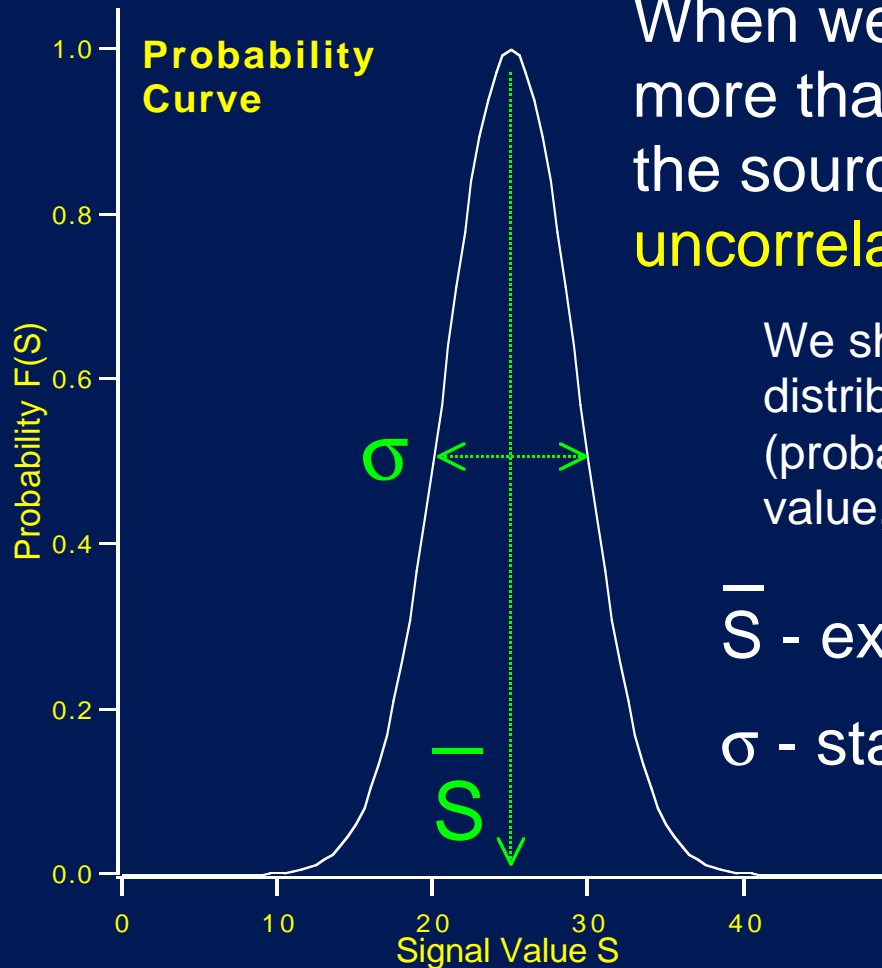
Noise affects the **precision** of the result.

Detection

Noise is always present on all signals!

We can only determine its magnitude by performing more than one measurement of the signal!

Signal Distribution Curve



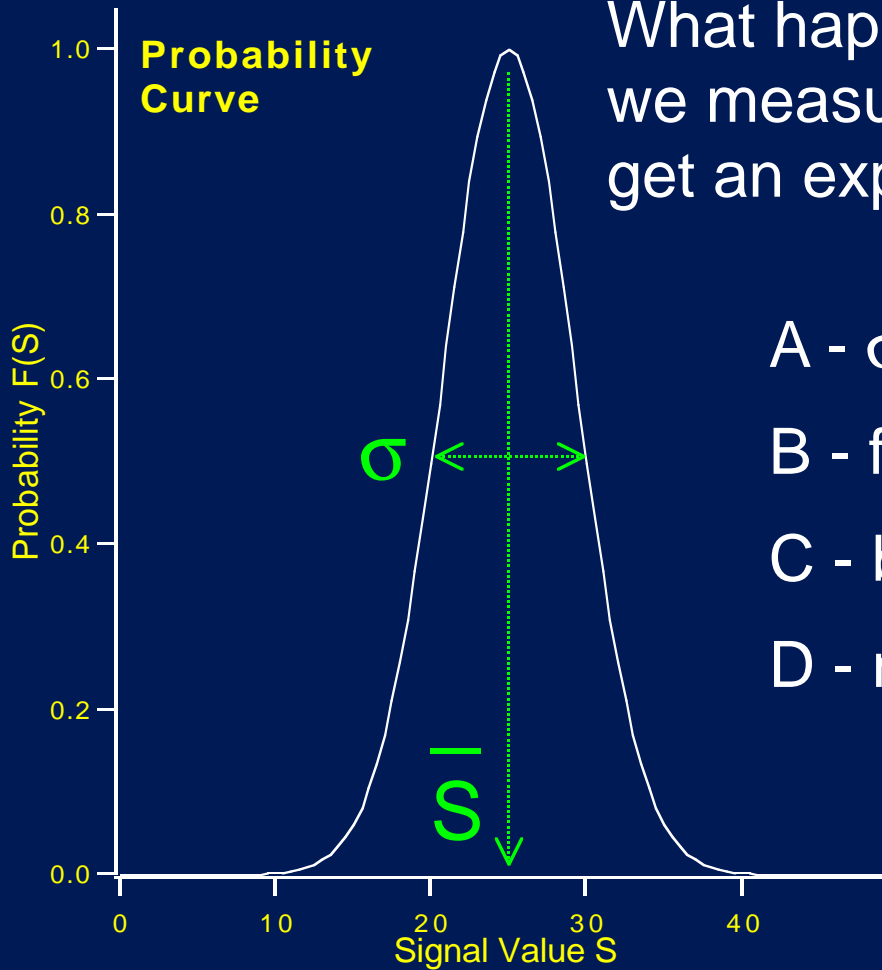
When we measure a signal more than once, we assume the sources of noise are **uncorrelated**.

We should obtain a Gaussian distribution in a plot of frequency (probability) of obtaining a signal value, $F(S)$, versus signal value, S .

\bar{S} - expected value

σ - standard deviation (noise)

Consequences?



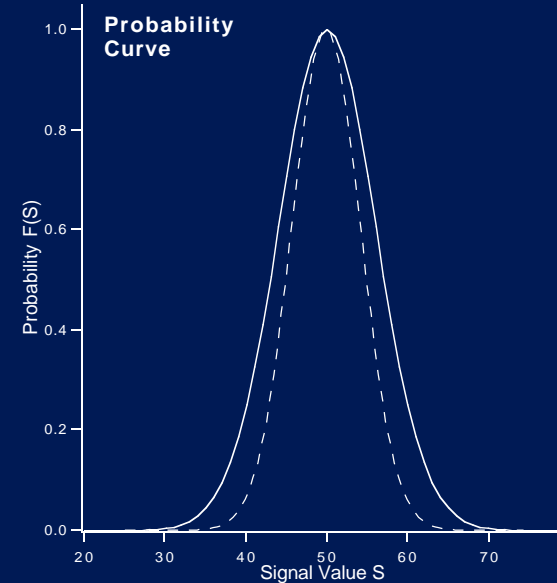
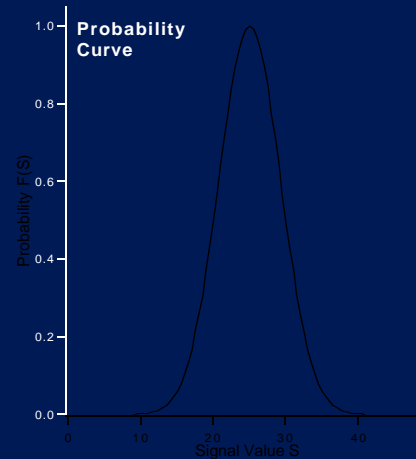
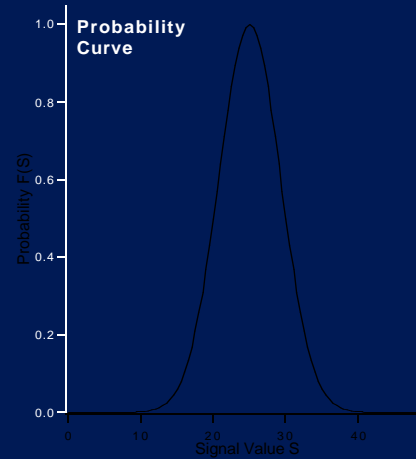
What happens to the curve when we measure for twice as long to get an expected signal that is $2 \underline{S}$?

- A - σ doubles
- B - f_{\max} doubles
- C - both of these
- D - none of these, rather...

Consequences

Measuring twice as long is equivalent to adding the two sampling distributions.

When noise is uncorrelated, the variances, σ^2 , add!



The resultant distribution is broader (but not twice as broad).

Result

Since variances, σ^2 , add each time we co-add a signal distribution, the magnitude of noise, σ , is dependent on the **square root** of the number of co-added distributions.

The amount of noise on a signal measured at a given channel is proportional to the square root of sampling time.

$$N \propto \sqrt{\Delta t}$$

Signal to Noise Ratio

The objective of a measurement in spectroscopy is to increase the signal to noise ratio, S/N.

$$S \propto \Delta t \qquad N \propto \sqrt{\Delta t}$$

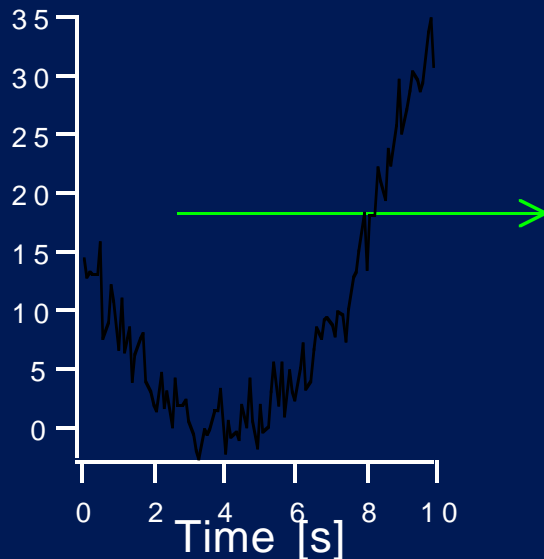
therefore

$$S/N \propto \sqrt{\Delta t}$$

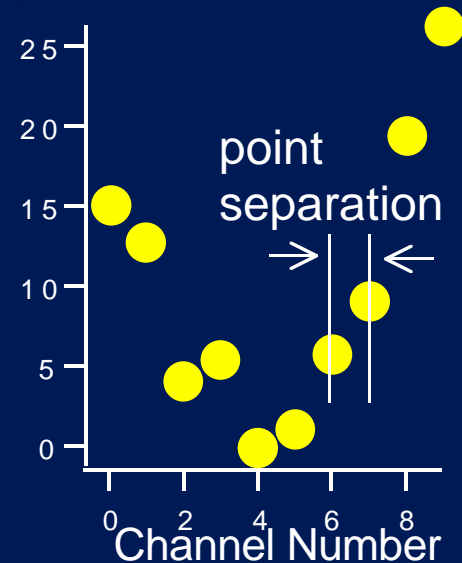
To double the S/N ratio, we must count four times longer.

Spectra

Most spectrometers record signals as a function of the independent variable in a **digital** mode rather than an **analog** mode.

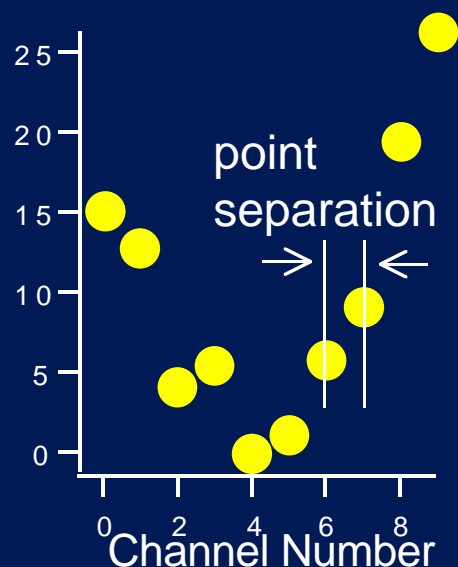


This is equivalent to using a chart recorder to take the signal.
continuous acquisition



The data are separated by a constant interval throughout the spectrum.

Digital Data Definitions



step size

The separation between points in the scale given.

sampling rate

The inverse of step size.

Channel number goes from 0 to $(n-1)$, where n is the number of points.

The measurement precision is half of the step size.

In AES and XPS, step size is in units of eV, and sampling rate is in units of points per eV.