# Electron-Spin Resonance (ESR)


## Abstract

Electron-spin resonance (ESR) spectroscopy deals with the *interaction of electromagnetic radiation with the magnetic moment of unpaired electron spins*. Due to its versatility ESR has found applications in a wide range of fields, from chemistry and biology to the novel and stimulating areas of quantum computation and "single-spin" detection.


### Objectives:

- Learn the basics of microwave spectroscopy.
- Learn the use and applications of lock-in amplifiers.
- By carrying out simple ESR measurements, determine the electron *g*-factor.

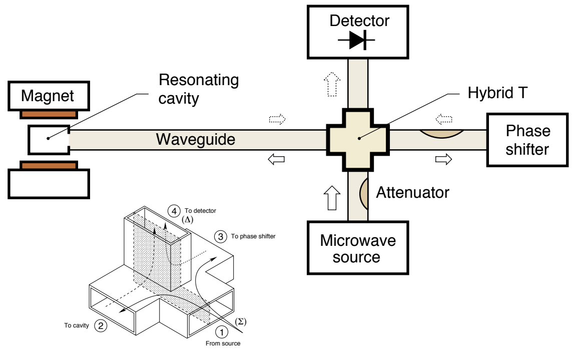
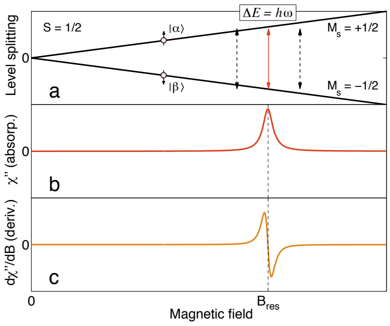



**Fig. 2:** Simplified diagram of the ESR spectrometer. The wave-guide system includes also a phase shifter, a hybrid junction (shown in detail) and two attenuators. Arrows indicate the propagation direction of the microwaves.




E. K. Zavoisky (1907-76)
discoverer of the ESR

**Fig. 1:** (a) The electron-spin Zeeman effect: progressive splitting of the $M_s = \pm ½$ spin states in an applied magnetic field. Only when the field is swept across the resonance ($\Delta E = g\mu_B H_0 = \hbar\omega$), there is a transfer of energy from the EM radiation (here at constant $\omega$), giving rise to an absorption line (b). In ESR the resonance is observed by detecting its derivative $d\chi''/dB$ (c).

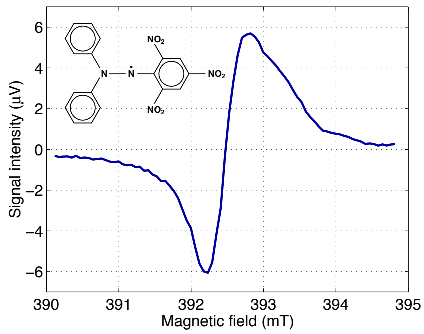



**Fig. 3:** Structure of the stable free-radical DPPH (2,2-diphenyl-1-picrylhydrazyl) (inset) and its ESR spectrum, as measured in the current experiment. A Gunn diode was used as a source of the X-band (9.75 GHz) radiation.

## Experimental approach

To detect the electron-spin resonance a DPPH sample (Fig. 3, inset) is positioned in a microwave cavity. Two sets of coils (Fig. 2) generate a (large) *static* $H_0$ and a (small) *modulating* $H_m$ magnetic field, respectively. When the main field is swept across the resonance, the sample absorbs EM radiation, hence spoiling the balance of the microwave bridge, previously tuned to provide a nil response in the microwave detector. At resonance, the weak signal generated in the diode detector is captured by the lock-in amplifier, whose output is recorded and displayed in a computer. Successive analyses provide the *width* and *position* of the ESR resonance, from which the g-value of the electron (typical of a given material) can be estimated.

## Results

The X-band ESR spectrum of a DPPH sample, measured in normal conditions (after magnet calibration), is shown in Fig. 3. The slightly asymmetric line-shape is due to the large sample volume. The evaluated *g*-value, 2.012(2), is within 0.4% from the accepted reference, and similar to that of free electrons.

### Further Reading


- C. P. Poole Jr., *Electron Spin Resonance* (Wiley, New York, 1983).
- D. M. Pozar, *Microwave Engineering*, 2nd ed. (Wiley, NY, 2001).
- J. A. Weil and J. R. Bolton, *Electron Paramagnetic Resonance*, 2nd ed. (John Wiley & Sons, Hoboken, NJ, 2007).
- M. R. Brustolon and E. Giamello, eds. *Electron Paramagnetic Resonance: A Practitioners Toolkit* (Wiley Hoboken, NJ, 2009).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