Observations of the Hyperfine Structure of Iron Using Mossbauer Spectroscopy

Shawn Westerdale

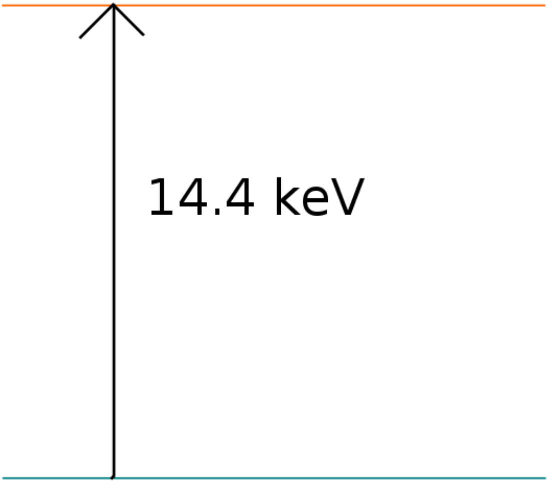
MIT - Department of Physics

Outline

- Goals & Objectives
- Perturbations of the Iron Hamiltonian
- Experimental Setup
- Observations
- Results
- Error Analysis

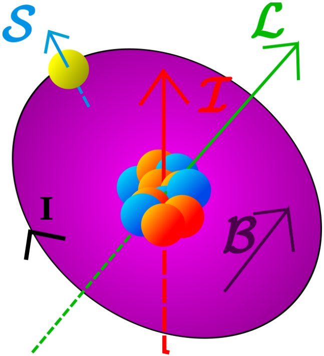
Goals & Objectives

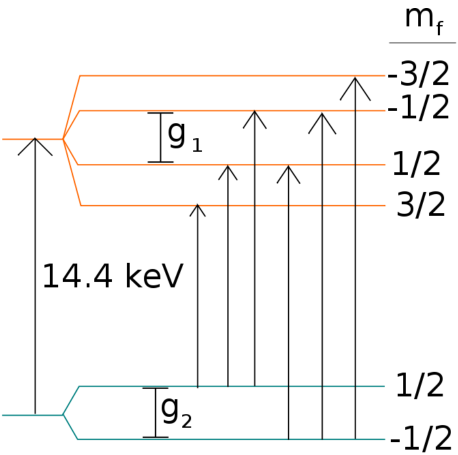
- Use Mossbauer spectroscopy to measure:
  - Zeeman splitting energy gaps
  - Magnetic moment of the first excited state
  - Intrinsic magnetic field at the nucleus
  - Isomer shifting
  - Electric quadrupole splitting


14.4 keV

Perturbations of the Hamiltonian

Hyperfine Zeeman Splitting



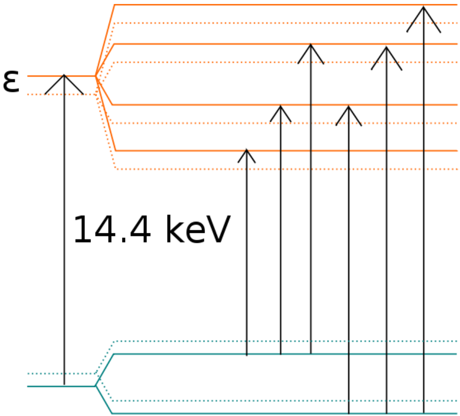


$$\mathcal{H}' = \vec{\mu} \cdot \vec{B}$$
$$= g_L m_f \mu_N B$$

Perturbations of the Hamiltonian

Isomer Shift

$$\Delta\mathcal{H}' = (g_L m_f - g'_L m'_f)\mu_N B + \epsilon$$



Perturbations of the Hamiltonian

Quadrupole Splitting

$$\Delta\mathcal{H}' = (\frac{3}{2}g_L - \frac{1}{2}g_L')\mu_N B + \epsilon - \delta$$

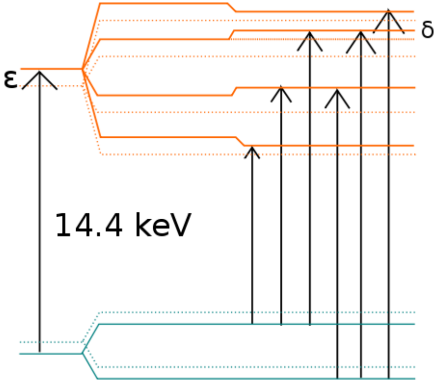
$$\Delta\mathcal{H}' = (\frac{1}{2}g_L - \frac{1}{2}g_L')\mu_N B + \epsilon + \delta$$

$$\Delta\mathcal{H}' = (-\frac{1}{2}g_L - \frac{1}{2}g_L')\mu_N B + \epsilon + \delta$$

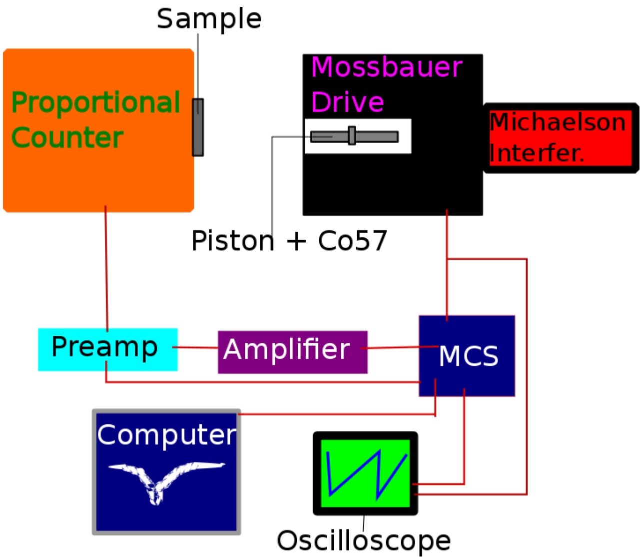
$$\Delta\mathcal{H}' = (\frac{1}{2}g_L + \frac{1}{2}g_L')\mu_N B + \epsilon + \delta$$

$$\Delta\mathcal{H}' = (-\frac{1}{2}g_L + \frac{1}{2}g_L')\mu_N B + \epsilon + \delta$$

$$\Delta\mathcal{H}' = (-\frac{3}{2}g_L + \frac{1}{2}g_L')\mu_N B + \epsilon - \delta$$

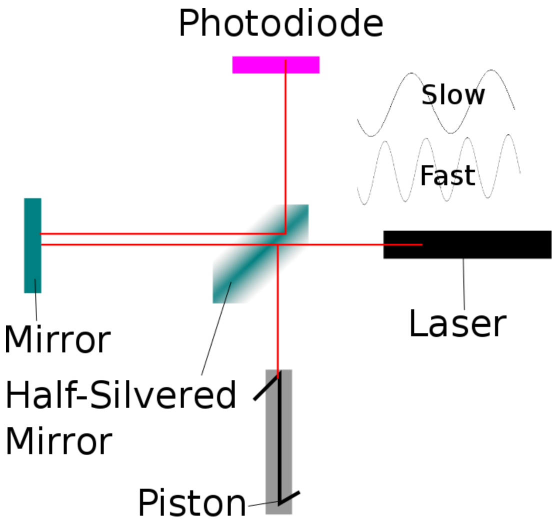


Experimental Setup



Experimental Setup

Michaelson Interferrometer



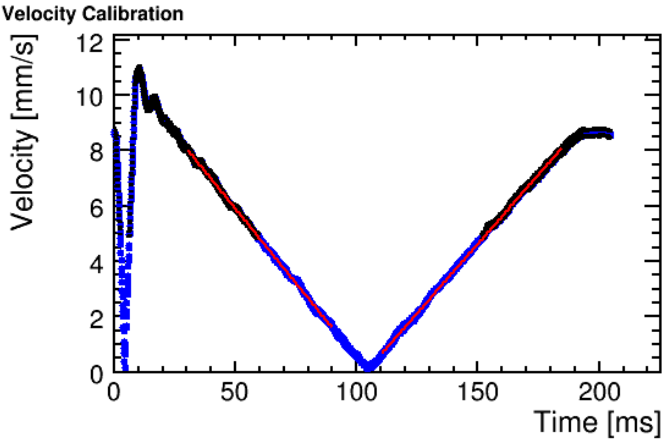
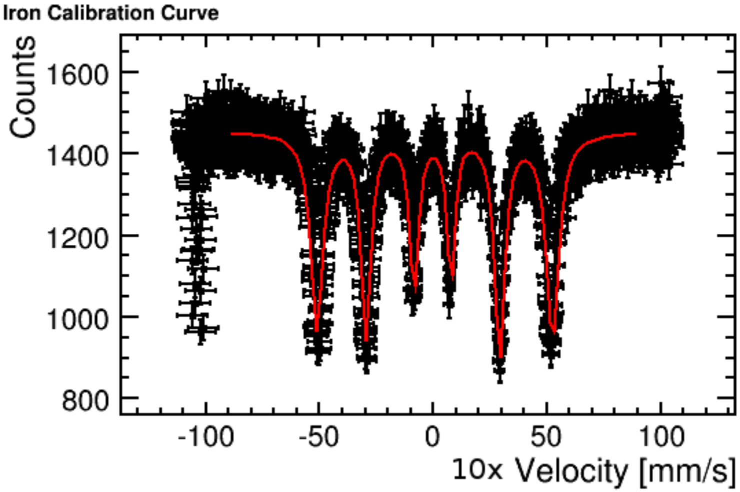


Figure: χ^2_{right}/NDF$=$ 0.85, χ^2_{left}/NDF$=$ 0.68

Observations

Metallic ^{57}Fe



Results

		Value	Accepted	Deviation
^{57}Fe [1]	g_0	$1.81 \pm 0.05 \times 10^{-7}$ eV	1.88×10^{-7} eV	1.4σ
	g_1	$1.06 \pm 0.04 \times 10^{-7}$ eV	1.08×10^{-7} eV	0.5σ
	$\frac{\mu_0}{\mu_1}$	1.71 ± 0.06	1.75	0.67σ
	ϵ	$0 \pm 3.89 \times 10^{-10}$ eV	0 eV	—
	δ	$0 \pm 2.88 \times 10^{-9}$ eV	0 eV	—
	B_N	317 ± 9 kOe	330	1.44σ
Fe_2O_3 [2]	g_0	$2.85 \pm 0.02 \times 10^{-7}$ eV	$2.93 \pm 0.02 \times 10^{-7}$ eV	3σ
	g_1	$1.68 \pm 0.03 \times 10^{-7}$ eV	$1.66 \pm 0.01 \times 10^{-7}$ eV	0.33σ
	$\frac{\mu_0}{\mu_1}$	1.70 ± 0.06	1.77 ± 0.01	1σ
	ϵ	$2.47 \pm 0.07 \times 10^{-8}$ eV	$2.26 \pm 0.14 \times 10^{-8}$	1σ
	δ	$1.66 \pm 0.78 \times 10^{-9}$ eV	$5.8 \pm 1.4 \times 10^{-9}$ eV	3.5σ
	B_N	$500. \pm 7$ kOe	513 ± 2 kOe	1.9σ

[1] R.S. Preston, Phys. Rev. v.128 (1962).
[2] O. Kistner, A. Phys. Rev Lett. v.4 (1960)

Error Analysis

- Total errors are small, $\approx 5\%$
- Three sources of random error dominated
  - Poisson errors: $\approx 2.5\%$
  - Calibration errors: $\approx 2\%$
  - Fitting errors: $\approx 0.3\%$

Conclusions

- Mossbauer spectroscopy allows for probing very low energy differences
- Measured hyperfine splittings and nuclear magnetic fields of ^{57}Fe and Fe_2O_3
  - Mostly agreed with published values
  - A few values varied with statistical significance

Acknowledgements

I would gratefully like to thank the Junior Lab faculty for helping us learn our way around this experiment and giving us advice along the way. I would also like acknowledge my parter D. Zou for working with me on the collection and analysis of this data.