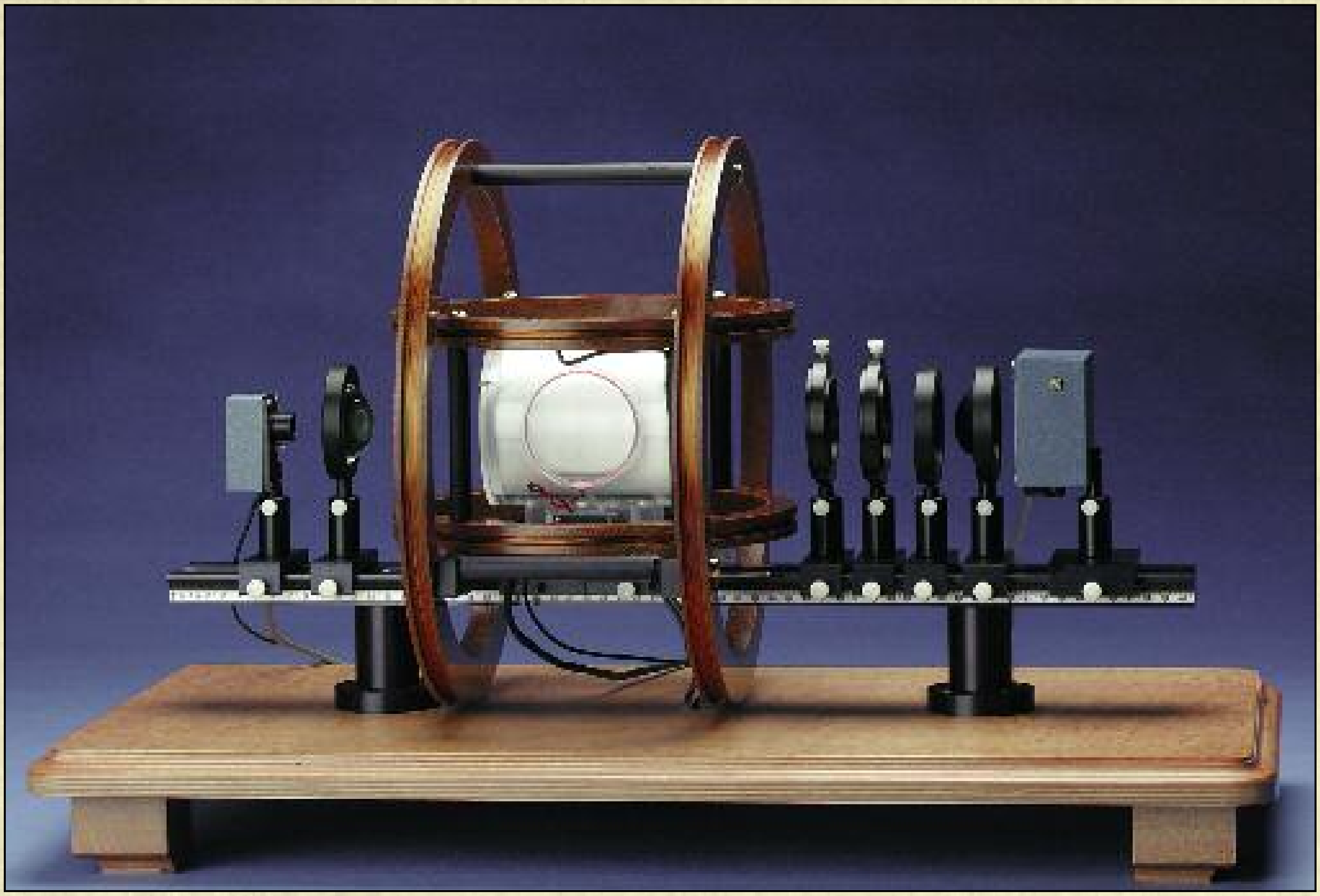
OPTICAL PUMPING



A "Course" in Atomic Physics

- Optical Pumping of Rubidium Atoms, Rb^{85} and Rb^{87}
- Explore Magnetic Hyperfine Interactions of Rubidium
- Observe Zero-Field Transitions
- Confirm Breit-Rabi Equation
- Observe Double Quantum Transitions
- Study Rabi Oscillations
- Measure Optical Pumping Times
- Study Temperature Dependence of Atomic Parameters

Instruments Designed For Teaching

TEACH SPIN

OPTICAL PUMPING OF RUBIDIUM VAPOR

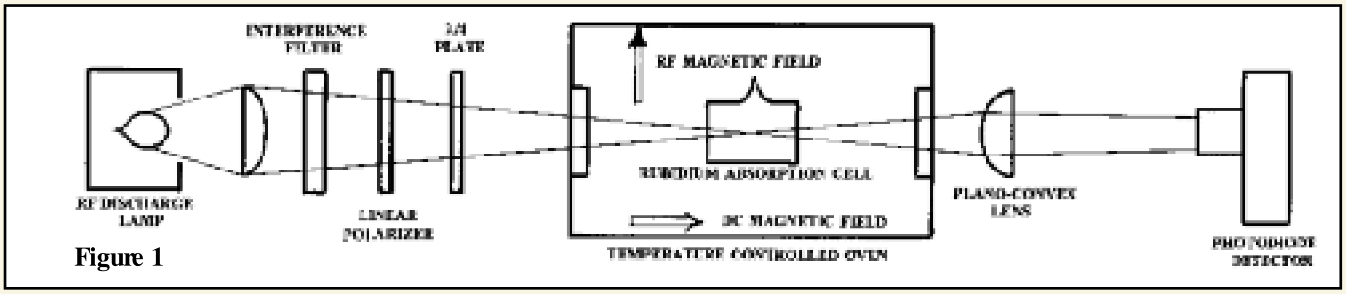


Figure 1

Optical Pumping is a widely used and powerful technique for exploring atomic energy states, atomic transitions, and atomic collisions using electromagnetism in the form of light, radio frequency, and uniform constant magnetic fields. TeachSpin's OP1-A explores the atomic physics of both isotopes of natural rubidium.

The rubidium atom is an ideal model system for students to study. Its energy states, in an externally applied uniform magnetic field, can be understood using a semi-classical model. This model describes the coupling of a single electronic orbital and spin angular momentum with the nuclear spin angular momentum and the interaction of the coupled system with the external field. The experimental determination of these atomic energy states can be compared to the theoretical predictions of the Breit-Rabi equation. The presence of two isotopes of rubidium, Rb^{85} and Rb^{87}, with different nuclear spins and magnetic moments, makes the experimental data even richer. OP1-A allows the student to explore a wealth of atomic physics, including the temperature dependence of photon absorption, zero magnetic field transitions, spin-spin collision processes, field inversion measurements, Rabi oscillation of the atomic magnetic moment, optical pumping times, and other atomic physics experiments. It is only a small exaggeration to claim that these experiments constitute a course in atomic physics .

THE INSTRUMENT

The basic features of the experimental set up are shown in Figure 1. Rubidium resonance light from a heated rf discharge lamp is collimated by a plano-convex lens and passes in an approximately parallel beam through an interference filter, so that only the 795 nm line ($^2S_{1/2}$-$^2P_{1/2}$) is transmitted. The light then passes through a linear polarizer and a quarter wave plate to produce a circularly polarized beam of light. This monochromatic, circularly polarized light passes into the oven and through the rubidium vapor absorption cell. The light is focused by a second plano-convex lens onto the photodiode detector.

The oven, with its absorption cell, resides inside two pairs of Helmholtz coils. The student must align the instrument so that the absorption cell's axis (the light path) lies along the horizontal direction of the local Earth's magnetic field. One Helmholtz pair is used to cancel the vertical component of the Earth's magnetic field. The second pair is used to create a uniform horizontal magnetic field in opposition to the horizontal component of the Earth's field. Transitions are induced among the atomic energy levels by the radio frequency magnetic field which is applied transverse to the optic axis. These transitions are observed as changes in the light intensity as measured by the photodiode optical detector.

STUDENT EXPERIMENTS

Students explore the interaction of the alkali atom with a weak magnetic field, as described by the theoretical perturbation calculations known as the Breit-Rabi equation. This equation is:

$$W(F,m) = -\frac{\Delta W}{2(2I+1)} - \frac{\mu_I}{I} Bm \pm \frac{\Delta W}{2}\left[1 + \frac{4m}{2I+1}x + x^2\right]^{1/2}$$

Where: $x = (g_J - g_I)\frac{\mu_0 B}{W}$ and $g_I = \frac{\mu_I}{I \mu_0}$

Here, W is the interaction energy, ΔW is the hyperfine splitting energy, and B is the externally applied magnetic field.

Figure 2 shows the optical pumping signals for zero and very low magnetic fields. Both the Rb^{85} and Rb^{87} isotopes produce only unresolved single lines in these low fields.

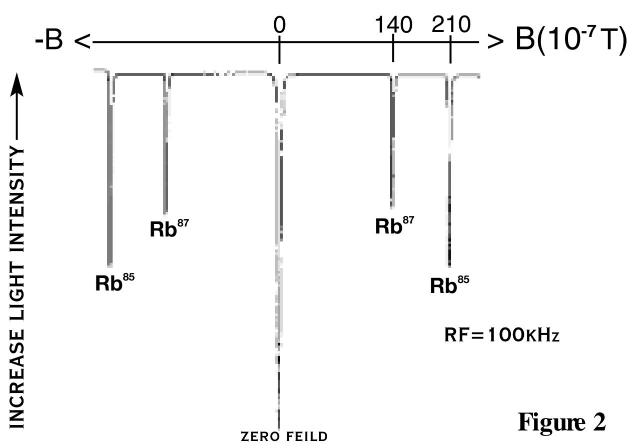


Figure 2

However, when the magnetic field is increased, each single line splits into resolved Zeeman lines, as shown in Figure 3. The data can be compared to the Breit-Rabi predictions. Double quantum transitions are also detected in this data. They can be studied as a function of rf power.

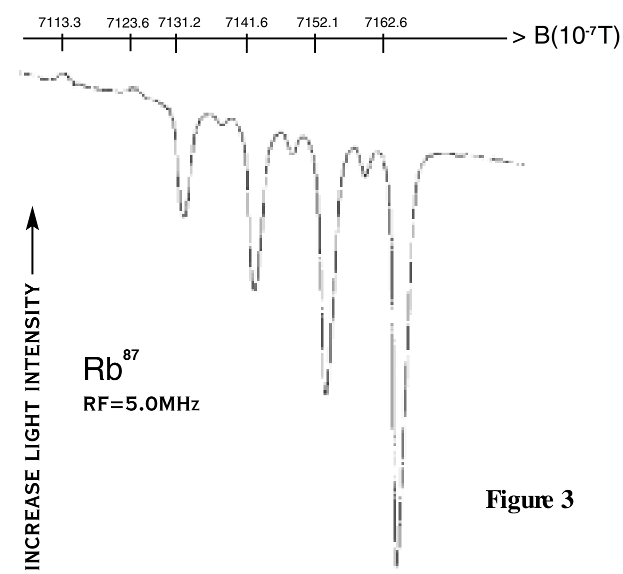


Figure 3

Both optical pumping times and the so-called Rabi oscillations can be studied by gating the rf power on and off at low magnetic fields.

Figure 4 shows a measure of the optical pumping time when the rf power has been turned off.

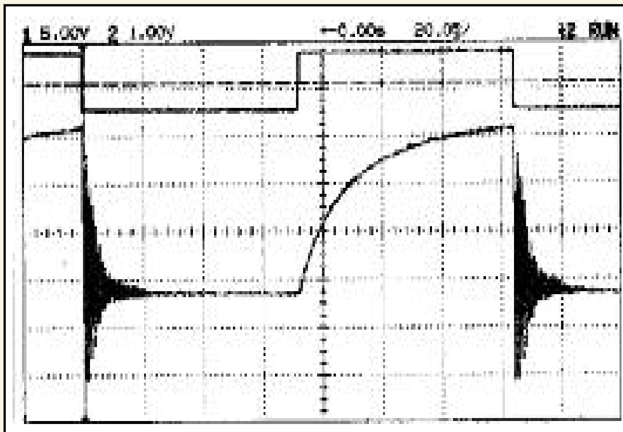


Figure 4

Figure 5 is an exploded view of the signal after the rf has been gated on. It clearly shows the oscillations of the transmitted light which are interpreted as precession of the atomic magnetization about the rf magnetic field. They can be studied as a function of rf power.

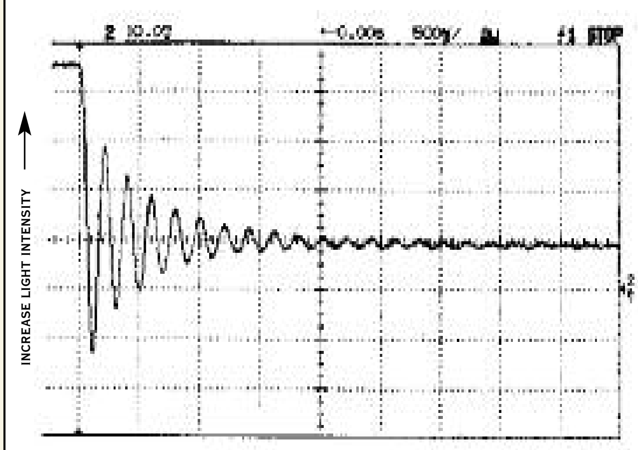


Figure 5

Other experiments include (but are not limited to) magnetic field reversal, photon absorption, spin exchange, effect of buffer gases on optical pumping, and temperature and light intensity dependence of the above. The instrument even includes a second mounted linear polarizer for students to study circularly polarized light.

ACCESSORIES

Included: • Black Cloth Shroud • Mounted Linear Polarizer • Instruction Manual

Additional:

- High Current Supply
- Different Absorption Cells
- RF Signal Generator
- Non-magnetic Table
- Circuit Diagrams
- Extended Warranty

SPECIFICATIONS

Absorption Cell: Natural Rb with 30 Torr Neon

Lamp: RF Discharge, Enriched Rb (63% Rb^{87})

Oven: PID Controller
Range: Ambient - 100 ˚C
Resolution: 0.1 ˚C, Reg. 0.05 ˚C/hr

Optics: (50 mm Diameter)
Interference Filter
2 Linear Polarizers and 1/4 λ Retarder in 360˚Rotation mounts
2 Plano-Convex Lenses, f = 50 mm

Photodiode Detector:
Low-noise Current-to-Voltage Preamplifier
Noise: 20 $\mu V_{p\text{-}p}$ with R_{gain} 1 MΩ
Bandwidth: 0.1Hz-1kHz

RF Amplifier: 10 kHz – 100 MHz
Input Impedance, 50 Ω
Output, 150 mW, 100 mA Max.

Detector Amplifier: Gain, 1, 2, 5,. . . 1000
Low-Pass, 12 db/oct
Time Constants: 1ms, 10ms . . . 3s

Dimensions:
Electronics 13" x 15" x 10"
Exp. Table 28" x 15" x 16"

Magnetic Field of Precision Helmoltz Coils:
Vertical: 0 – 1.4 x 10^{-4} T,
Stability, 2 x 10^{-7} T/hr,

Horizontal: 0 - 8 x 10^{-4} T (internal supply)
0 - 22 x 10^{-4} T (external supply)
Stability, 4 x 10^{-7} T/hr
Homogeneity > 0.02% over cell

Horizontal Sweep: 0 – 6 x 10^{-5} T,
Time; 1, 2, 5 . . . 1,000s
Stability; 2 x 10^{-7} T/hr

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