PHYSICS 510

EXPERIMENT S-10

OPTICAL PUMPING

Cornell University
Physics Department
410, 510 Laboratory

Physics 510

Experiment S-10 Optical Pumping

The object is to observe, study and understand optical pumping in the resonance transitions of rubidium vapor in a weak magnetic field. Besides studying the field dependence of the Zeeman splittings, the earth's field will incidentally be determined. The apparatus may also be used to study the dynamic response of spins to time varying magnetic fields and to illustrate the contrast between the sudden and adiabatic approximations of quantum mechanics.

1) Measure the g values for both isotopes of rubidium and compare with the theoretical predictions. Simultaneously you should be able to measure accurately the earth's magnetic field.
2) From the shape of the optical pumping signal determine the characteristic time required to establish the steady state polarization of the spins. Does this time depend upon the light intensity?
3) Note that there is an apparent "resonance" when the field is swept through zero (applied field cancelling the earth's field) in absence of an r.f. field. Explain these signals qualitatively in terms of adiabatic and sudden passage through zero field.
4) Work at fixed r.f. frequency, enhancing the amplitude of the r.f. field by resonating the r.f. coil with a small capacitor, and demonstrate quantitatively the distinction between sudden and adiabatic passage through the resonance.

References:

Bloom: Scientific American, October 1960
Benumot: Am. Jour. Phys. 33, 151, 1965
de Zafra: Am. Jour. Phys. 28, 646, 1960
Special notes - RHS, 1972

Also see:

Herzberg, "Atomic Spectra" - on the Zeeman effect generally and the vector model of the atom.
White, "Introduction to Atomic Spectra", p. 373-376 - on the g - factor in the presence of a nuclear spin.
"Optical Pumping: An Introduction", edited by R.A. Bernheim, a Benjamin reprint volume.
Rabi, Ramsey and Schwinger, "Use of Rotating Coordinates in Magnetic Resonance Problems", Rev. Mod. Phys. 26, 167, 1954.

Circuit

The measurement of "resonance" between the applied rf-field and the Zeeman split sub levels is not done by sitting on the resonance (why not?). Instead a "sweep" current added to the D.C. current feeding the Helmholtz coils will produce a "wobbling" of the total magnetic field and get you into and out of resonance at twice the "sweep" frequency (Audio oscillator). The circuit provides a trapezoidal sweep for the principal pair of Helmholtz coils (#1) as well as a variable d.c. current for the two pairs of coils (#2 and #3) used to trim the transverse field to zero. The trapezoidal sweep is characterized by the 4 independently controlled parameters indicated in the sketch:

1) Sweep period by the oscillator frequency
2) Ramp rate by "Rate"
3) Range by the left hand control marked #1
4) I_{min} by the right hand control marked #1

(The Range and I_{min} are not entirely independent.) The operation of the sweep may be verified by displaying on the second CRO using a linear time base. For display of the optical pumping signal, it is useful to use both a linear time base to the X axis and to drive the X axis with the monitor signal from the coil sweep. In this second mode, it is most satisfactory to use the d.c. X axis amplifier.

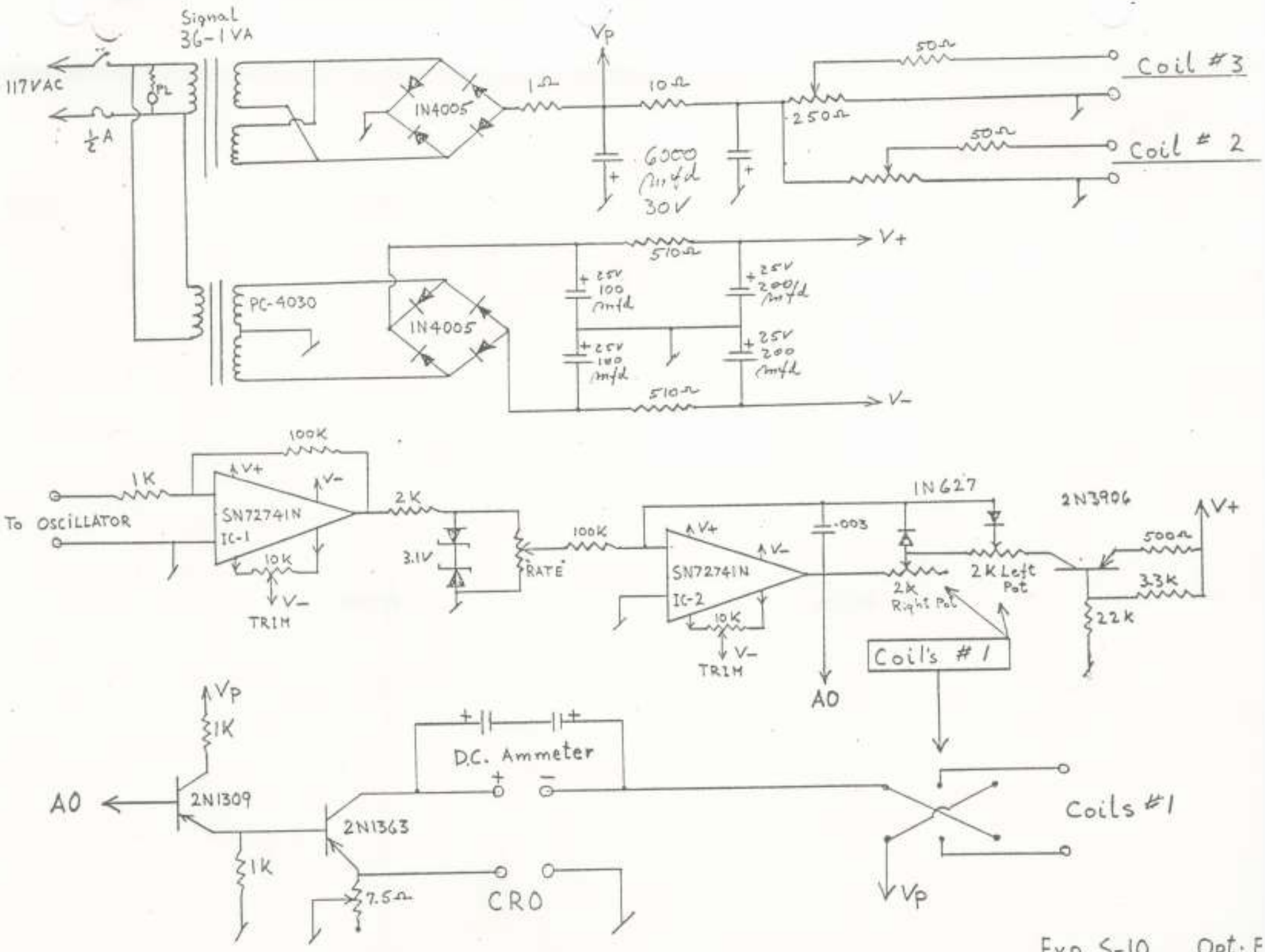
Note that it is possible to generate a triangular sweep by reducing the sweep rate and/or increasing the sweep repetition rate and range until the sweep is reversed before the clamping diodes on the integrator are operative. This triangular sweep is useful to display the adiabatic passage when one wishes to spend more time on one side of the resonance than the other.

Resonance of the r.f. coil is achieved at roughly the following frequencies when resonated with:

.001μf → 1.4 MHz

.01 μf → 480 KH_z

.1 μf → 160 KH_z


Signal
36-1VA
117VAC
½A
IN4005
1Ω
Vp
10Ω
6000 mfd
30V
50Ω
250Ω
Coil #3
Coil # 2
V+
510Ω
PC-4030
IN4005
25V 100 mfd
25V 200 mfd
25V 100 mfd
25V 200 mfd
V-
100K
1K
To OSCILLATOR
SN72741N
IC-1
V+
V-
10K
TRIM
2K
3.1V
RATE
100K
IN627
2N3906
.003
SN72741N
IC-2
2K Right Pot
2K Left Pot
500Ω
3.3K
22K
Coil's #1
AO
Vp
1K
AO
2N1309
2N1363
D.C. Ammeter
1K
7.5Ω
CRO
Coils #1
Vp

Exp S-10 Opt: F

Comments on Use of S-10 Notes

You have to know about

(a) The Principle of Optical Pumping

Read the Scientific American Article by A. Bloom "Optical Pumping". Then, more directed towards your experiment, the article by De Zafra "Optical Pumping". If you need help with understanding atomic spectra terminology or "g-factors" read Feynman's paragraph 34-2 "Magnetic moments and angular momentum" and/or Atomic Spectra by Fowler, chapter 7 of "Introduction to Modern Optics" or Herzbergs book, "Atomic Spectra and Atomic Structure", chapters I/5, II/1 and II/3 (Zeeman effect). This will do for parts (1) and (2) of your assignment.

(b) Dynamic Response of Spins to Time Varying Magnetic fields.

This is for parts (3) and (4) of your assignment. Read Silsbee's Notes: "Dynamic Response of Spins to Time Varying Magnetic Fields" (Special Notes S-10) in back of this booklet. See also the article by Benumoff.

There is also a reprint book "Optical Pumping" in the Reading Room 3rd Floor.