

### III. FAR INFRARED SPECTROSCOPY

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#### A. SENSITIVITY AND RESPONSE CHARACTERISTICS OF THE GOLAY PNEUMATIC DETECTOR

##### 1. Introduction

The use of hot untuned sources in far infrared spectroscopy places stringent demands upon the sensitivity of the devices used for detection of the signal, due to the fact that the spectral power from the hot source falls off rapidly with increasing wavelength (the spectral radiance of the source decreases by a factor of  $10^4$  per decade). The conventional detector used in the far infrared is the Golay pneumatic cell, which is operated at room temperature and therefore is limited in sensitivity by the temperature noise inherent in any device used at  $300^\circ\text{K}$ . Improvement in detectivity could be expected only if the operating temperature were decreased. For this reason, the study of low-temperature detectors – in particular the carbon and doped germanium bolometers operated at  $1.5^\circ\text{K}$  – was initiated and has been carried out over the last two years,<sup>1</sup> in cooperation with Professor R. C. Lord of the Spectroscopy Laboratory, M.I.T. In the course of these studies it has become increasingly evident that a great deal of additional information about the Golay cell is required if it is to be used effectively as a standard of comparison

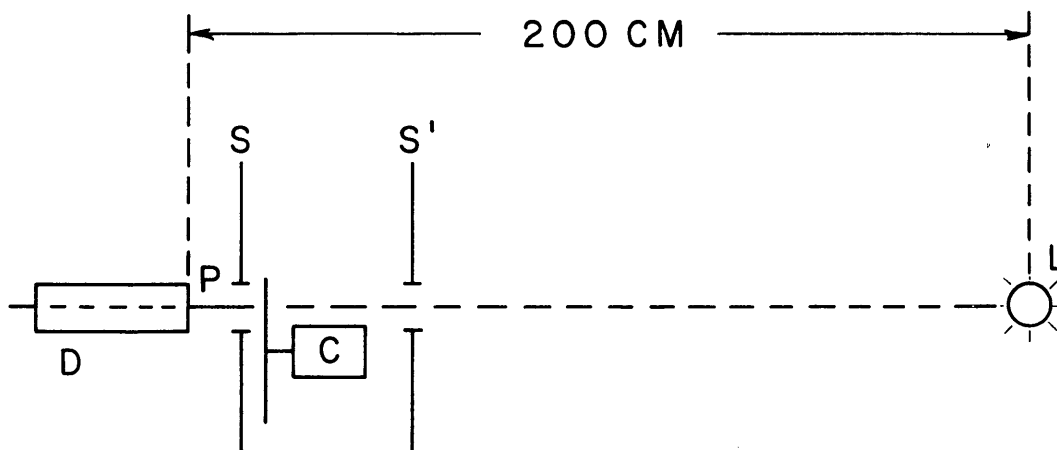


Fig. III-1. Optical layout for Golay tests.

- D Detector
- P Pinhole aperture (0.03-cm diameter)
- S,S' Screens
- C Variable-frequency chopper
- L Radiation standard (N. B. S. C-350 standard lamp)

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for new types of detectors.

This report describes the measurement of the detectivity ( $D^*$ ) and the responsivity as a function of signal frequency for several typical Golay cells that are now in use in our far infrared grating instruments and in our Michelson Interferometer.

#### 2. Experiment

The optical system used is shown in Fig. III-1. The signal source consists of a National Bureau of Standards Type C-350 standard lamp for which the total radiant flux at a distance of 200 cm is given as a function of filament current. The detector, fitted with a 0.03-cm diameter pinhole, is located at a distance of 200 cm from the lamp. Radiation from the lamp is modulated by a rotary sector which chops the radiation at a frequency that is continuously variable from 2 to 80 cps. Two screens are placed as shown in the figure to minimize the chopped radiation received by the detector from background sources. (Since the chopper blade is itself at ambient temperature, 300°K black-body radiation is not modulated and hence is not included as part of the signal.)

The noise equivalent power (NEP) of the detector is defined<sup>2</sup> as that rms signal power incident upon the detector which will give a signal-to-noise ratio of unity when the system bandwidth is 1 cps. That is,

$$\text{NEP} = \frac{NJa}{S(\Delta f)^{1/2}} \text{ watts} \times \text{sec}^{1/2},$$

where

$J$  = rms value of the fundamental component of incident radiant flux in watts/cm<sup>2</sup>,

$a$  = pinhole area =  $7.06 \times 10^{-4}$  cm<sup>2</sup>,

$S$  = rms value of the fundamental component of the signal voltage in volts,

$N$  = rms value of detector noise in volts, and

$\Delta f$  = equivalent noise bandwidth of detector and electronic system in cps.

If  $I$  is the calibrated DC flux from the source, then the rms value<sup>3</sup> of the fundamental component of the incident flux,  $J$ , is

$$J = \frac{\sqrt{2}}{\pi} I.$$

Hence, the NEP of the detector can be obtained by measuring the signal-to-noise ratio at the filtered output of the amplifier at a known effective system bandwidth  $\Delta f$ .

The detectivity,  $D^*$ , is defined as the reciprocal of the noise equivalent power of the detector, normalized to unit detector area.<sup>4</sup>

$$D^* = \frac{A^{1/2}}{(\text{NEP})} \text{ cm watt}^{-1} \text{ sec}^{-1/2}$$

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where A is the detector area ( $7.06 \times 10^{-2} \text{ cm}^2$  for the Golay cells used in all tests).

The effective response time of the Golay detector is estimated by measuring the relative responsivity of the detector as a function of chopping frequency. The responsivity is normalized to unity at the conventional 13-cps chopping frequency used in the far infrared spectrometer. For an ideal thermal detector with a time constant  $\tau_1$ , the absolute responsivity (the ratio of the rms value of the fundamental component of signal voltage to the rms value of the fundamental component of incident radiation power<sup>2</sup>) is of the form<sup>5</sup>

$$r(f) = \frac{r_0}{(1 + 4\pi^2 f^2 \tau^2)^{1/2}}$$

as a function of frequency f. The Golay detector is not, however, an ideal thermal detector, since it is characterized by both thermal and mechanical response characteristics in addition to a low-frequency cutoff that results from the ballasting of the cell. The value

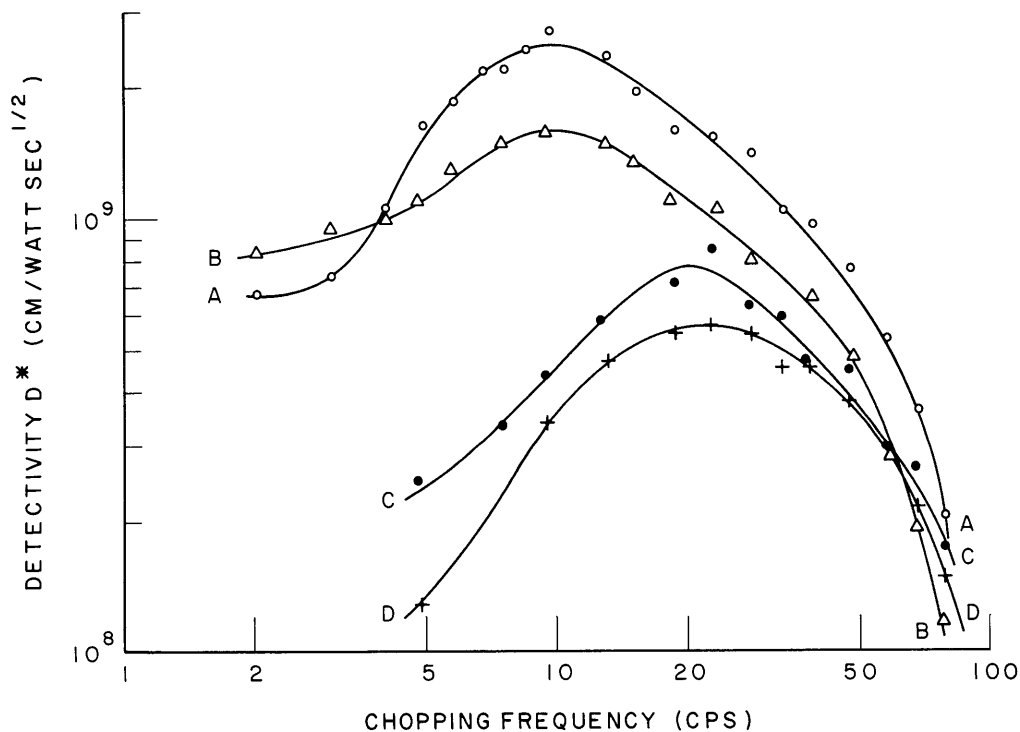


Fig. III-2. Sensitivity vs chopping frequency for several Golay detectors.

A.	Unicam	No. 29787
B.	Unicam	No. 28697
C.	Eppley	No. 2301
D.	Eppley	No. 1490

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of the time constant of the Golay detector is therefore dependent upon a suitable operational definition in terms of the measured response vs frequency curve. The "effective time constant,"  $\tau_E$ , as defined and used here, is the time constant of that ideal thermal detector whose responsivity curve most closely approximates that measured for the Golay detector.

The electronic system consists of a Tektronix 123 battery-operated low-level pre-amplifier and a Perkin-Elmer type 107 amplifier. Signal rectification is achieved by using a mercury relay that is driven at the chopping frequency by a photocell pickoff on the chopper. The demodulated output is filtered by the standard RC filter network in the P. E. 107 and is recorded on a Leeds-Northrup Speedomax Recorder. The system bandwidth is determined by the selected time constant of the amplifier.

#### 3. Results

The data obtained for two Eppley Golay cells and two Unicam Golay cells are presented in Figs. III-2, III-3, and III-4. It is seen that the Eppley detectors have a peak detectivity of  $8 \times 10^8 \text{ cm watt}^{-1} \text{ sec}^{-1/2}$  at a chopping frequency of about 20 cps, and that operation at 20 cps represents an improvement of almost 50 per cent over the performance at the usual 13-cps chopping frequency. Time constants for the two Eppley detectors

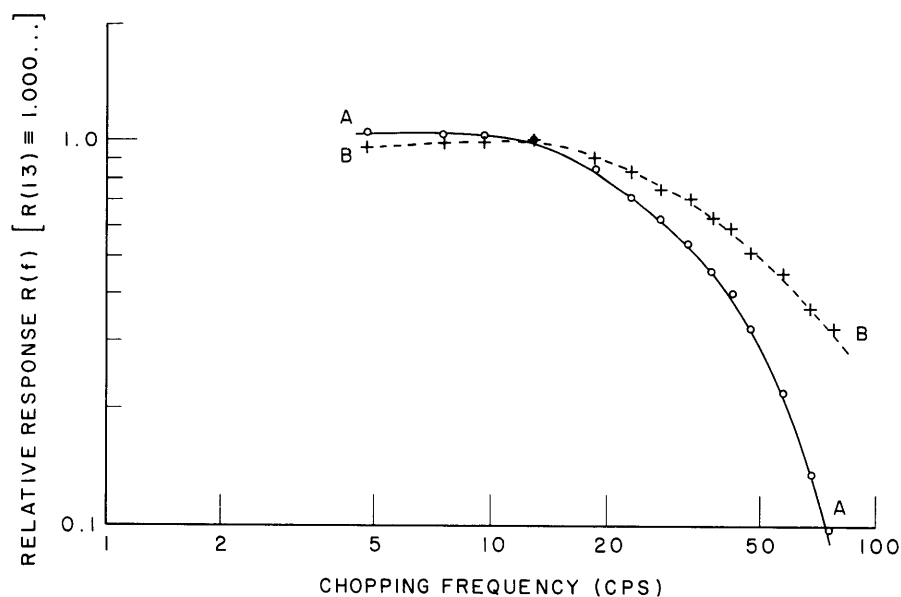


Fig. III-3. Relative response vs chopping frequency  
Eppley Golay cell No. 2301.

A. Detector and electronics

B. Detector only

$$\tau_E = 6 \times 10^{-3} \text{ sec}$$

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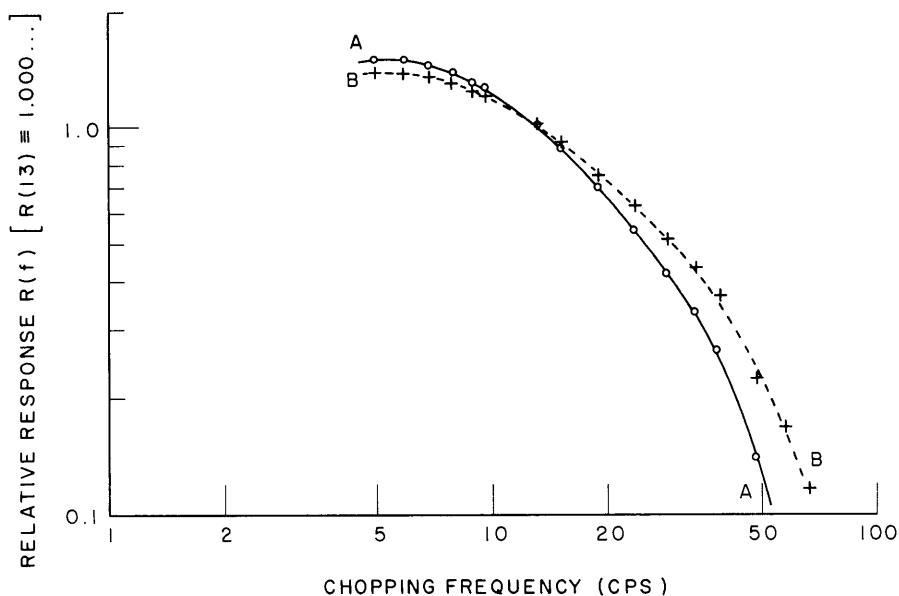


Fig. III-4. Relative response vs chopping frequency  
Unicam Golay cell No. 29787.

A, Detector and electronics  
B, Detector and preamplifier unit only

$$\tau_E = 3 \times 10^{-2} \text{ sec.}$$

were found to be 6.8 msec for No. 1490 and 6.0 msec for No. 2301.

The two Unicam Golay cells, furnished with the FS-S20 Interferometer, were tested and compared with Eppley cells. In all cases the detector area is  $7.06 \times 10^{-2} \text{ cm}^2$ , and the window material is diamond. It is seen that the peak detectivity of the Unicam cells is between two and three times that of the Eppley cells. The ratio of the time constants is correspondingly about 5 to 1, which is consistent with the conclusion<sup>6</sup> that the sensitivity of the Golay detector is proportional to  $\tau^{-1/2}$ . The longer time constant, and hence the lower optimum frequency (10 cps) of the Unicam detectors make them more suitable for operation at 13 cps.

#### 4. Conclusions

The above results agree within a factor of  $\sim 1.5$  with the results obtained by Potter and Eisenman.<sup>2</sup> In both cases, measurements were made in the near-to-intermediate infrared, and hence give only an approximate indication of performance in the far infrared. The absorbing film on the Golay window is designed to make the detector "gray," i. e., equally responsive to all wavelengths greater than  $\sim 0.5\mu$ . We are currently planning to make responsivity and detectivity measurements as a function of wavelength in order

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to establish the "grayness" of the Golay cell and make it usable as a comparison standard for similar measurements with newer types of detectors.

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