

DETECTION OF METHANE COMBUSTION WITH APPLICATIONS TO
QUENCHING COAL MINE EXPLOSIONS

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ABSTRACT

A device developed by the U.S. Bureau of Mines for the detection and quenching of coal mine explosions suffers from the inability to discriminate between the light emitted from hydrocarbon combustion and that emitted by electrical sparks and miner's cap lamps. Since the quenchant device is activated by an internal explosive charge, the possibility of serious injury to nearby personnel demands a detector which can reject false signals. Described herein is a device which can provide a rapid response signal upon the emission of radiation from hydrocarbon combustion and concurrently reject spurious signals from such sources as sparks and cap lamps.

NOMENCLATURE

B_{λ}	Planck blackbody function - watts/cm ² -μ
I	intensity - watts/cm ²
$J_{\Delta\lambda}$	spectral emission coefficient for bandpass $\Delta\lambda$ - watts/particle
n_{OH}	number density of OH particles - particles/cm ³
V	volume - cm ³
μ_{λ}	absorption coefficient - cm ⁻¹ particle ⁻¹
ω	solid angle - steradians

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INTRODUCTION

The accumulation of methane gas in a coal mine constitutes an ever present explosion hazard. The methane is a by-product of the decomposition process which forms the coal. If the concentration of methane in air reaches the critical range of approximately 5-12 percent an explosion can occur. Methane levels are customarily controlled by forced ventilation, but this is not completely successful in preventing localized concentrations in the critical range.

An explosion takes a finite time period (on the order of milliseconds) to develop after ignition of the methane. The U.S. Bureau of Mines has developed a device for detecting and quenching the developing explosion by discharging potassium bicarbonate in its path (refs. 1 and 2). However, the device is unable to discriminate between light emitted from methane combustion and that emitted by electrical sparks or miner's cap lamps. Since the quenchant device is dispersed by an internal explosive charge, the possibility of serious injury to nearby personnel demands a detector which can reject false signals. It was suggested by R. L. Trimpi, Assistant Chief, Hypersonic Vehicles Division, Langley Research Center, that this difficulty might be surmounted by developing a detector which would operate on the principle of monitoring the radiation intensity emitted from two separate spectral regions and ratioing the intensities. Such a detector would provide a rapid response signal after sensing the emission of radiation from the hydrocarbon combustion and concurrently reject spurious signals from sparks and cap lamps due to the differences in the spectral characteristics of the emissions.

A series of experiments are described for methane-air combustion which illustrate the validity of such an approach. Estimates of the spectral irradiance of the combustion event are presented, thereby determining the required sensitivity of the device.

EXPERIMENTAL APPARATUS

A cylindrical (3.8" diameter x 12") stainless steel shock tube test section was used as a combustion chamber. The test section was equipped with quartz windows (2" diameter) on either side, a piezoelectric pressure transducer, and two steel electrodes. A 10 kilovolt capacitor discharged across the electrodes provided a sub-microsecond duration spark to ignite the gas mixture within.

The desired partial pressures of methane and air were obtained by using a Wallace and Tiernan 0-800 mm Hg pressure gauge with which pressures could be determined to an accuracy of 1/2 mm Hg. All tests were conducted with a total pressure of 1 atmosphere in the chamber. The time history of the wall pressure was measured during combustion with a Kistler Model 701 Quartz Pressure Transducer and Charge Amplifier.

The radiation emitted during combustion was observed with Jarrell Ashe 1/4 meter monochromators placed symmetrically on either side of the test section. The monochromator dispersion was $33 \text{ \AA}/\text{mm}$ and both entrance and exit slits were 500μ in width. Radiation emerging from the exit slits was detected with RCA 1P28 photomultiplier tubes. A Philbrick Model Q3M1P operational amplifier was used to ratio the output voltage from the two spectral channels. All signal voltages were recorded on Tektronix Models 551 and 556 oscilloscopes.

A schematic diagram of the experimental apparatus is shown in figure 1.

RESULTS

A survey of the flame spectrum of methane showed that a particularly strong emission occurred from the OH O-O band head at 3064 \AA , and that a region of relatively low emission existed nearby at 3000 \AA . Several ignitions were performed with the monochromators set on these channels to check consistency, and in all cases were found to repeat well, with an approximate intensity ratio of 6:1, and a peak wall pressure of 75 psia. An oscilloscope trace made during one of these tests in a stoichiometric mixture of methane and air is shown in figure 2.

Next, a series of ignitions was carried out in which the initial partial pressure of methane was varied through the combustion range of 5-12 percent. In these tests, it was found that the 6:1 intensity ratio was approximately maintained, even though the relative intensities varied considerably with initial CH_4 concentration. A plot of relative peak intensity for both channels as a function of initial partial pressure of methane is shown in figure 3, along with the peak wall pressure variation.

Figures 4 and 5 illustrate the electronic ratio of the signals of the two spectral channels. The records of figure 4 were made with the monochromators at the normal test configuration 6 inches from the test section centerline, while those of figure 5 correspond to a position 18 inches from the centerline. It is seen that even though the relative intensities have been greatly reduced, use of the operational amplifier to divide the incoming phototube signals minimizes the variation of output signal as a function of source detector distance.

For light sources emitting radiation in both channels, such as the incandescent lamp continuum on the many-line spectrum of iron, the signal ratio should be significantly reduced. Figure 6 shows the individual channel outputs for a 200 watt tungsten lamp and the corresponding ratioed signal from the operational amplifier. Similar results are obtained for an iron arc source, as shown in figure 7.

The components used in the "bread-board" experiment immediately suggest the use of more compact and less expensive spectral ratioing devices as a hydrocarbon combustion detector. For example, narrow band interference filters placed in front of solid-state photodetectors equipped with an electronic divider circuit could be operated from a central power supply or optionally from a self-contained battery pack. Electronic dividers are commercially available in wafer size integrated circuits, as are 25 Å bandpass filters in this wavelength region.

In order to assess the sensitivity requirements of such a prototype, the intensity, I, received at the detector may be approximated by the following:

$$I \approx \frac{n_{OH} \omega V}{4\pi} \int_{\Delta\lambda} \mu_{\lambda} B_{\lambda} d\lambda \equiv \frac{n_{OH} \omega V}{4\pi} j_{\Delta\lambda}$$

where $j_{\Delta\lambda}$ is the integral over the specified bandpass (.3064 - .3089 μ) of the emission coefficient of an OH particle and is a function of temperature only. This function has been calculated from the absorption coefficient tabulations of reference 3 and is presented in figure 8.

This information, along with the number density of OH particles in burning volume V at temperature T, and the solid angle, ω , subtended

by the detector, may be used to approximately determine the sensitivity requirement of a photodetector. Reference 4 gives typical mole fractions of OH as .02 at flame temperature 1960° K for a methane-air mixture at 1 atm. pressure. Choosing a representative volume of 28400 cm³ (1 ft³) and solid angle of 10⁻⁵,

$$I = \frac{1}{4\pi} [7.5(10)^{16} \cdot 10^{-5} \cdot 2.84(10)^4 \cdot 10^{-23}] = 10^{-8}$$

The RCA 1P28 photomultipliers used have a photosensitivity rating of about 50 ma/watt at .3μ and a current gain of 2 (10)⁵. This results in a cathode current of .1 ma, which through a 10 K output resistor supplies 1 volt signal to the divider, which is more than adequate.

CONCLUSIONS

It has been demonstrated that methane combustion produces much greater emission near .3064 μ than at .3000 μ, whereas electric sparks and incandescent lamps possess nearly constant emission levels in these spectral regions. Therefore, a detection scheme based on the ratio of the emission at these wavelengths can discriminate between methane combustion and the interjection of an incandescent lamp or an electric spark in the optical field of view. Estimates of the spectral irradiance of methane combustion have been made and indicate adequate detector sensitivity for representative conditions.

Although these experiments were conducted for CH₄ combustion, the detection apparatus should respond similarly for other hydrocarbon combustion processes due to formation of the OH radical.

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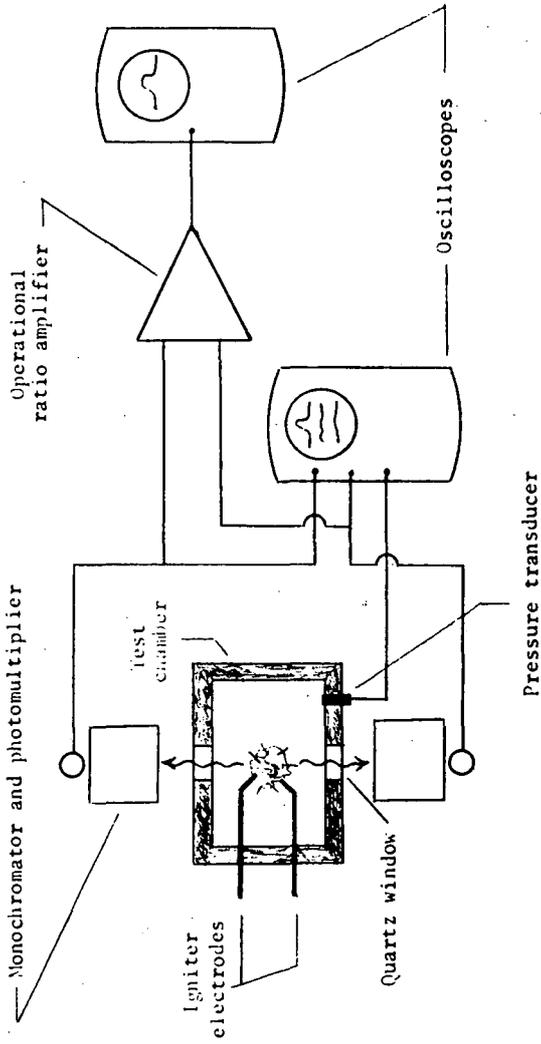


Fig. 1. Schematic diagram of experimental apparatus.

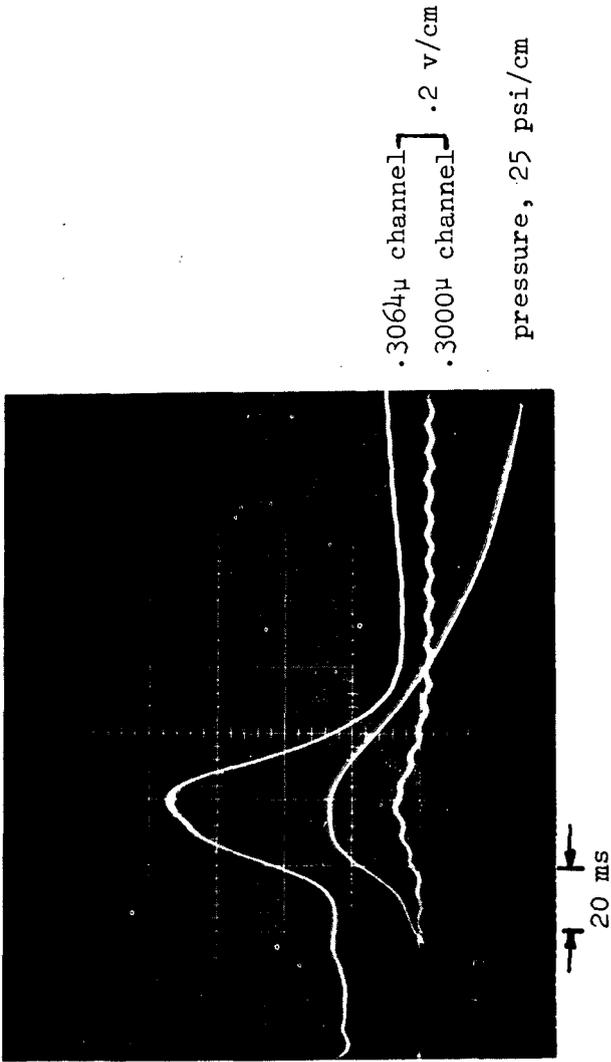


Fig. 2. Photomultiplier outputs and pressure transducer signal for typical combustion.

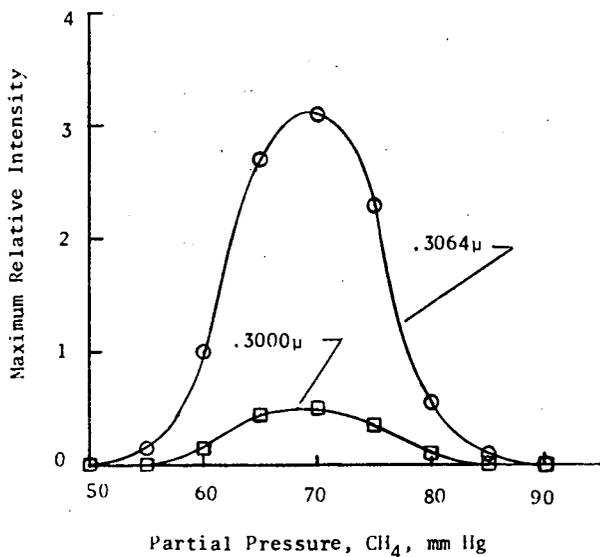
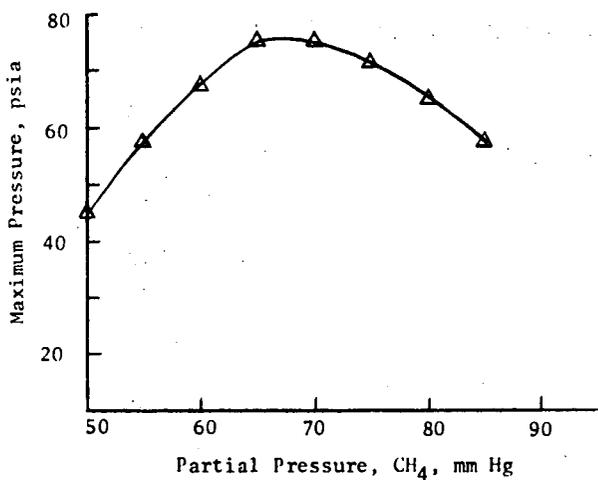


Fig. 3. Plots of peak spectral intensities and maximum pressures as functions of initial partial pressure of CH₄ in air.

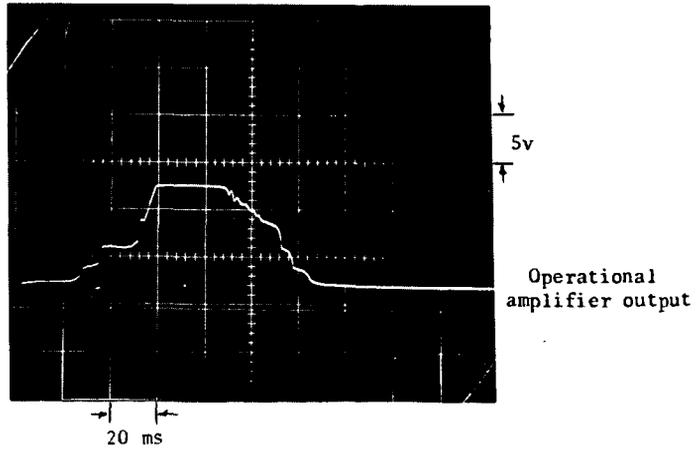
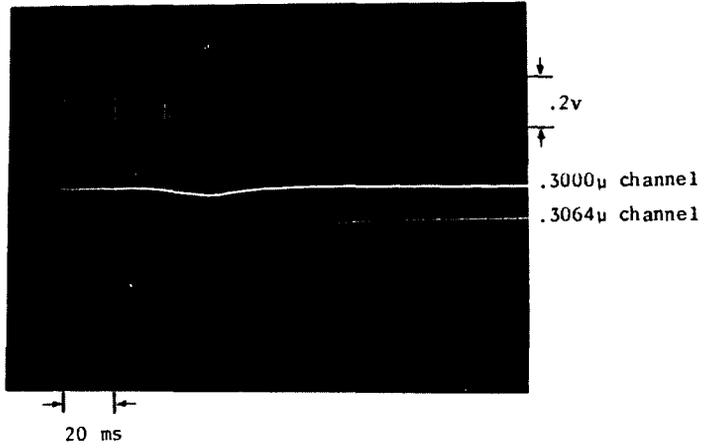


Fig. 4. Record of spectral intensities and output of electronic ratio amplifier during typical combustion test.

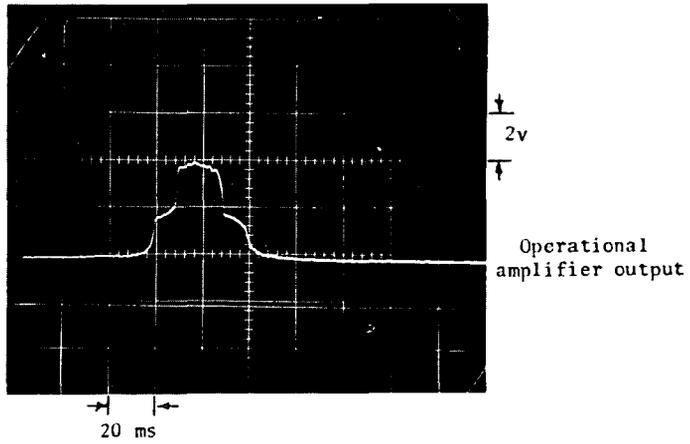
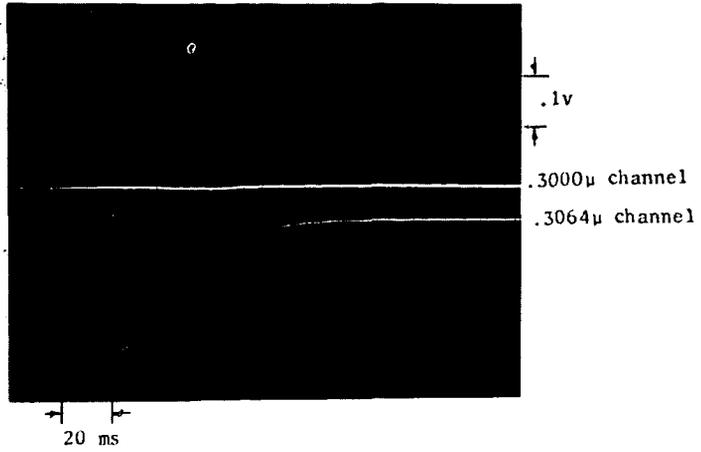


Fig. 5. Record of spectral intensities and output of ratio amplifier with reduced intensity on spectral channels.

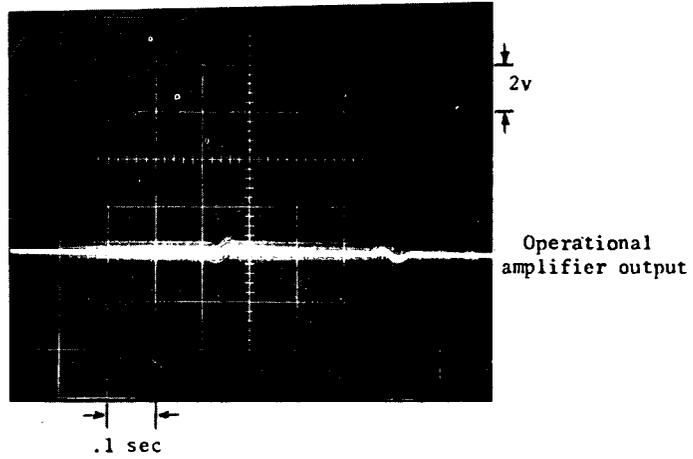
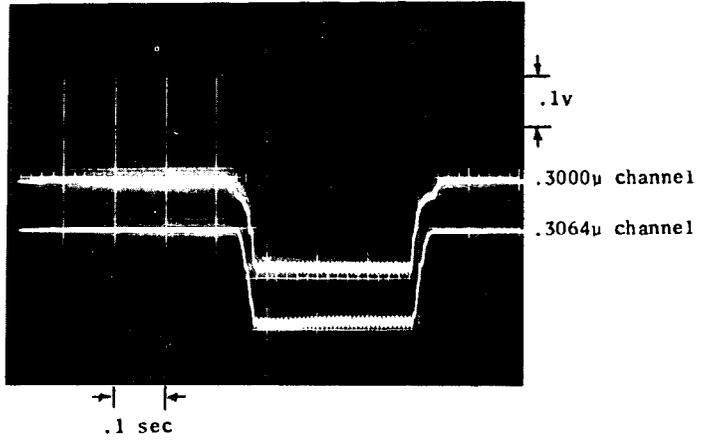


Fig. 6. Spectral signals and output of ratio amplifier for incandescent lamp.

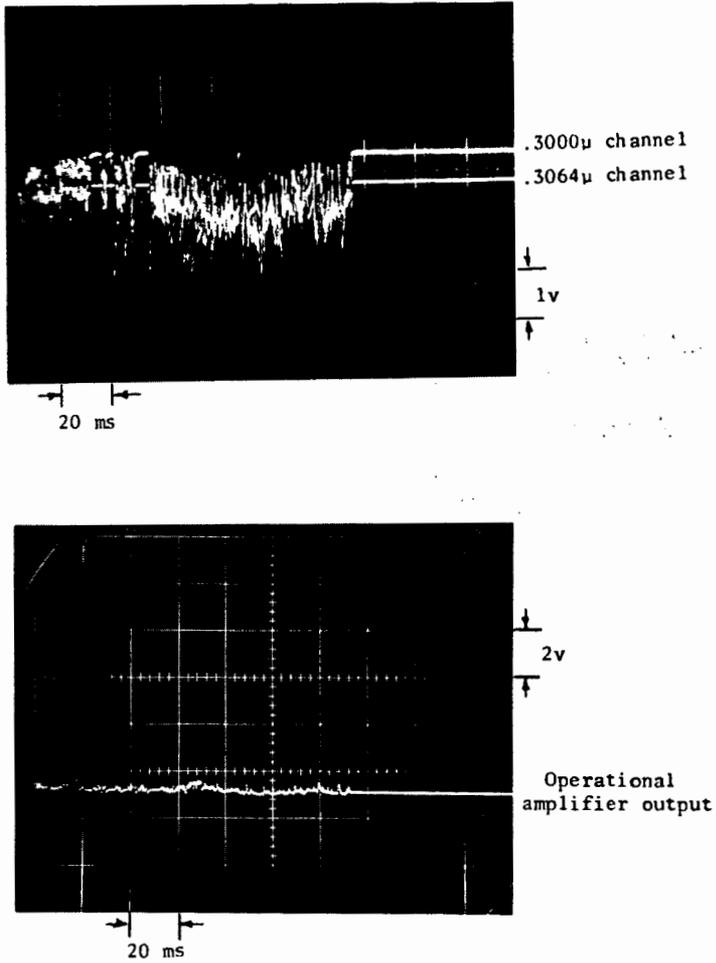


Fig. 7. Spectral signals and ratio amplifier output for iron arc source.

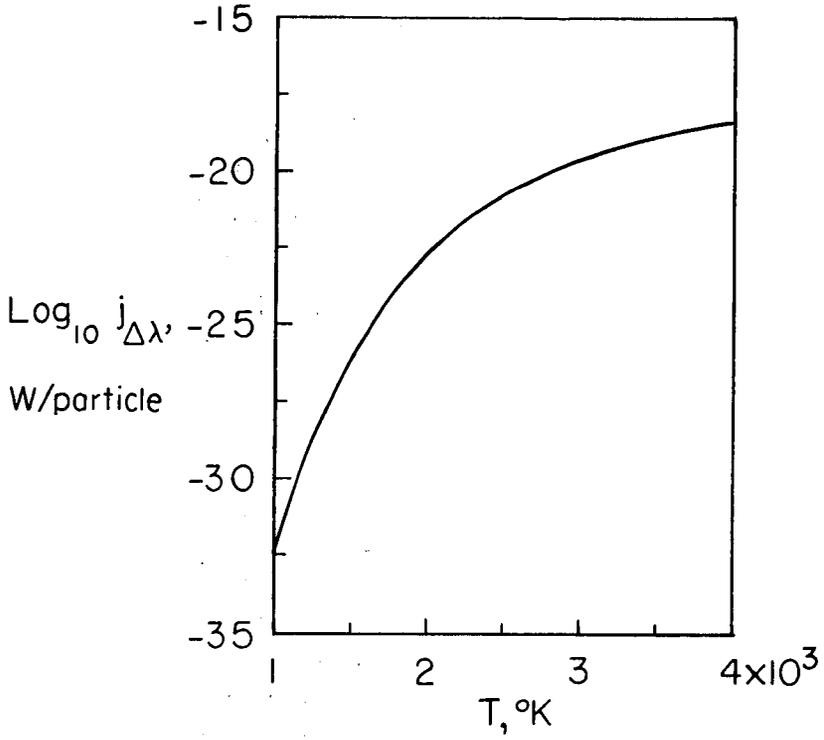


Fig. 8. Spectral bandpass energy per OH particle as a function of temperature.