MEETINGS AND CONFERENCES

Scientific session of the division of general physics and astronomy, USSR Academy of Sciences

(Submitted September 27, 1973)
Usp. Fiz. Nauk 113, 327–330 (June 1974)

A scientific session of the Division of General Physics and Astronomy of the USSR Academy of Sciences was held on September 27, 1973 at the Conference Hall of the USSR Academy of Sciences Institute of Physics Problems. The following papers were delivered:

1. T. P. Belikova, É. A. Sviridenkov, and A. F. Suchkov, Ultrahigh-Sensitivity High-Speed Laser Spectroscopy of Radicals and Molecules.

2. I. M. Podgornyĭ, É. M. Dubinin, and Yu. N. Potanin, Investigation of Precipitation of Particles and Formation of a Radiation Belt in Terrella Experiments.

We publish below brief contents of the papers.

T. P. Belikova, É. A. Sviridenkov, and A. F. Suchkov. Ultrahigh-Sensitivity High-Speed Laser Spectrocopsy of Radicals and Molecules. The use of lasers in spectroscopy has made possible a sharp increase in the frequency and time resolution attainable in spectral investigations. This paper reports on a new method of laser spectroscopy that gives a sharp increase (by 5–6 orders of magnitude) in the sensitivity of absorption spectroscopy.

It is possible to obtain absorption (amplification) spectra of gases with absorption coefficients $\lesssim 10^{-7}$ cm^{-1} in experiments. Multipass cells with optical lengths of several kilometers are used to investigate weak absorption lines in absorption spectroscopy. In such cells, the length of the optical path traveled by the light is limited by the design complexity of cells with large linear dimensions and losses on reflection at the mirrors. The optical paths actually obtained range up to ~ 50 km at a cell length ≈ 1 km.

The proposed method makes it possible to attain optical paths of $\sim 10^6$ km with a cell a few tens of centimeters long. A lsser resonator is used as the multipass cell in this case. The amplification by the active substance in the resonator offsets the losses at the resonator mirrors and enables the laser light to cover a long effective path in the substance under study by multiple reflection. Even extremely weak absorption lines are brought out in the generation spectrum. In this case, the laser active medium is the light source and offsets losses. To prevent distortion of the absorption spectrum of the substance inside the resonator by properties of the laser, it is necessary that the gain of the active medium remain constant at all lasing frequencies, and that the radiation intensity be constant at all frequencies in the absence of matter.

A theoretical analysis[1] indicates that active substances with an inhomogeneously broadened amplification band exhibit frequency-constant gain in the lasing process. If a medium that has an absorption line at frequency ω_0 with absorption coefficient $\Delta k(\omega)$ and width $\Delta\omega$ is placed in the resonator of such a laser, the relative change in the lasing intensity $\Delta I(\omega)/I_{av}$ at the frequency ω_0 will be

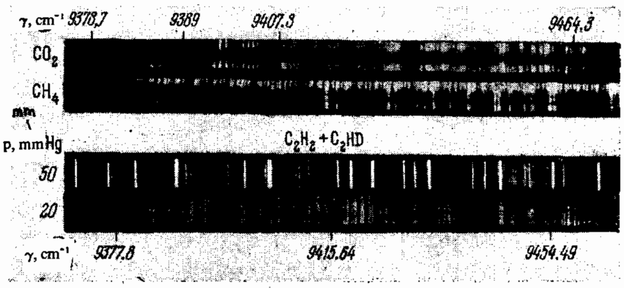
$$\frac{\Delta I(\omega)}{I_{av}} \sim \frac{\Delta k(\omega) L}{\alpha} (\beta + \eta e^{-2\pi\gamma/\Delta\omega})^{-1}, \quad (1)$$

where L is the length of the resonator, α are the frequency-independent radiation losses in the resonator on one pass, β is the ratio of the spontaneous-emission power to the power of the radiation generated in one mode of the laser resonator, η is the excess of pump power over threshold, and γ is the homogeneous broadening of the working transition in the active medium of the laser.

The most typical laser with an inhomogeneously broadened amplification band is that in which the active medium is glass doped with Nd^{3+}. If the usual parameters of such a laser are substituted into expression (1) ($L \sim 10^2$ cm, $\alpha \approx 0.1$, $\beta \sim 10^{-4}$ to 10^{-6}, $\eta \sim 1$, $\gamma \approx 20$ cm^{-1}), it becomes evident that this laser can be used to register absorption lines of a gas with an absorption coefficient $\Delta k \sim 10^{-7} - 10^{-9}$ cm^{-1} in the resonator if the absorption line width $\Delta\omega \sim 0.1$ cm^{-1}.

This high sensitivity makes it possible to detect very faint absorption lines, but at the same time it requires special care in the conduct of experiments. Lines due to absorption not only in the substance under study, but also in unaccountable impurities may appear in the generation spectrum of the laser, as well as interference effects due to reflection in scattering of light by elements of the resonator. It is these effects that usually endow the generation spectrum of the neodymium laser with its random and nonreproducible structure. Some authors have reported that line structure in the generation spectra is a fundamental property of Nd^{3+}-glass lasers[2].

We succeeded in obtaining a structureless generation spectrum after thorough elimination of unaccountable frequency-dependent resonator losses. To obtain a smooth spectrum, it is necessary that no more than



≈ 10^{-8} of the incident energy enter the resonator as a result of diffraction on microscopic inhomogeneities and dust particles or by reflection from the back surfaces.

All selecting elements were eliminated from the resonator, and the mirrors were deposited on bases 3 cm thick with the back surface 10° out of parallel. The Nd^{3+}-glass rod was cut at the Brewster angle, one of its faces forming a window of the cell, whose other window was the resonator exit mirror. When test gases were admitted into the cell, we obtained their absorption spectra in the lasing range of Nd^{3+} (9360–9460 cm^{-1}) with absorption coefficients of 10^{-3} to 10^{-7} cm^{-1}. The figure shows a few absorption spectra as examples.

The high sensitivity of the proposed method makes it possible to work with microscopic amounts of the substances analyzed, an important point for study of isotope-substituted compounds (the figure shows the spectrum of C_2H_2 + C_2HD).

The proposed method will be used to model the optical properties of planetary atmospheres and the interstellar gas, to investigate atmospheric pollution, and in the analytical chemistry of gases. The maximum attainable sensitivity is 10^{-11} cm^{-1}, which corresponds to a molecule concentration of ~ 10 cm^{-3}.

The high intensity of the laser radiation makes it possible to obtain the absorption spectra in very short times. The speed of the method is limited by the propagation velocity of light, i.e., the time during which the light covers the effective absorbing-layer thickness $\tau = L_{eff}/c$. Times $\tau \sim 10^{-7}$ to 10^{-3} sec are required to investigate absorption spectra with $\Delta k \sim 10^{-3}$ to 10^{-7} cm^{-1}. This permits the use of the method to study nonstationary processes in chemistry and the intermediate products of chemical reactions: radicals and excited states of molecules.

It is interesting to note the possibility of registering not only weak absorption lines, but also the amplification in excited molecules. Amplification lines of the CH radicals formed on photolysis of the C_2H_2 + C_2HD mixture are clearly visible in the figure.

This method could be extended over practically the entire visible and near infrared region of the spectrum by the use of organic-dye lasers.

---

[1]T. P. Belikova, É. A. Sviridenkov, A. F. Suchkov, L. V. Titova, and S. S. Churilov, Zh. Eksp. Teor. Fiz. 62, 2060 (1972) [Sov. Phys.-JETP 35, 1076 (1972)].

[2]V. S. Mashkevich, Zh. Eksp. Teor. Fiz. 53, 1003 (1967) [Sov. Phys.-JETP 26, 601 (1968)]; V. I. Malyshev, A. V. Masalov, and A. A. Sychev, ZhETF Pis. Red. 11, 324 (1970) [JETP Lett. 11, 215 (1970)].

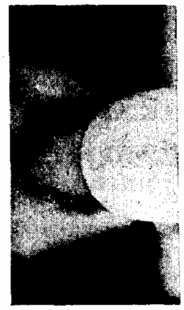


FIG. 1

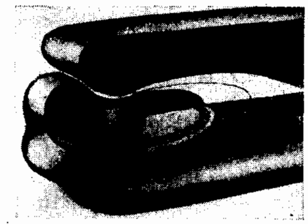


FIG. 2

FIG. 1. Blackening of film placed in the meridional plane on the daytime side. The breakthrough of particles through the polar gaps and the radiation belt are clearly visible.

FIG. 2. Model of magnetosphere.

I. M. Podgornyĭ, É. M. Dubinin, and Yu. N. Potanin. Investigation of Precipitation of Particles and Formation of a Radiation Belt in Terrella Experiments. It was shown earlier [1,2] that, despite the impossibility of reproducing the complete picture of the interaction of the solar wind with the earth's magnetic field in the laboratory, a number of the most important phenomena can be studied in model experiments. The limited-modelling principle was used in selecting the experimental conditions: although the dimensionless parameters determining the course of the phenomenon to be studied differed somewhat from their values in space, this could not produce significant differences. At an artificial solar wind velocity $\bar{v} = 3 \times 10^7$ cm/sec, a concentration $n = 10^{13}$ cm^{-3}, an electron temperature T_e = 15 – 20 eV, and a field B = 30 G frozen into the plasma, the interaction of the plasma stream with the magnetic field of the dipole resulted in the formation of a magnetosphere with a magnetic tail and other features characteristic of the earth's magnetosphere. A collisionless shock wave in which the microfluctuation spectrum agreed with that measured in space [2] was registered on the daytime side.

The magnetosphere obtained in the model experiment was used to study the penetration of fast particles into the earth's magnetic field and their precipitation into the upper atmosphere. A small number ($n \cdot 10^{-4}$) of fast electrons were injected into the artificial solar wind; the paths on which they entered the magnetosphere and struck the surface of the terrella were investigated for the most part with x-ray films. The penetration of the plasma in the region of the so-called neutral points on the daytime side was clearly evident on exposure of films placed in the plane of the dipole axis and the velocity of the undisturbed plasma stream. Penetration on the night side occurs at lower latitudes. Measurements showed that the regions of penetration on the day and night sides are interrelated. They form a gap that girdles the terrella and is enclosed between the force lines of the closed magnetosphere and the lines going out into the magnetic tail. There are two of these polar gaps—north and south. The penetration of fast particles into these gaps results in their precipitation onto the surface of the terrella precisely at the point where, according to Brice and Hartz, a high-latitude auroral zone should be observed. Another (low-latitude) precipitation zone is also observed in the model experiment. Its appearance is associated with particles trapped in the magnetic field and drifting around the axis of the terrella. In other words, a radiation belt