A. OPTICAL FREQUENCY STANDARD

Joint Services Electronics Program (Contract DAAB07-75-C-1346)

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We have taken test spectra of Na$_2$ in a supersonic molecular beam consisting primarily of Ar or Ne. Use of a supersonic molecular beam has two advantages: the Doppler width of the transition is reduced because the beam motion is perpendicular to the laser beam, and the gas expansion cools the molecules into the lowest vibrational and rotational states. A sample spectrum is shown in Fig. IV-1.

![Spectrum of seeded Na$_2$ molecular beam near 6020 Å. Negative (positive) marker pulses are separated 0.019 Å (0.159 Å).](image)

The test spectra show a 0.002 Å linewidth. From day to day, the line position varies approximately ±0.001 Å (100 MHz).
B. VELOCITY DEPENDENCE OF ENERGY TRANSFER CROSS SECTIONS

Joint Services Electronics Program (Contract DAAB07-75-C-1346)
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We have measured the velocity dependence of fine-structure changing cross sections between Na and the target gases Ne, Ar, Kr, Xe, N₂, and CO₂. These measurements were made with the use of our technique of velocity selection based on the Doppler shift, which permits the measurement of the velocity dependence of collision cross sections in a gas cell, in contrast to the usual and more cumbersome crossed molecular beam machines. Typical results are shown in Fig. IV-2 for the process

\[ \text{Na}(3P_{1/2}) + \text{Xe} \rightarrow \text{Na}(3P_{3/2}) + \text{Xe} - \Delta E \]

where \( \Delta E \) is the amount of translational energy that goes into exciting the fine structure.

Fig. IV-2. Velocity dependence of Na-Xe fine-structure changing cross section for \( j = \frac{1}{2} \rightarrow j = \frac{3}{2} \). Lower section shows rms velocity resolution achieved by our velocity-selection Doppler-shift (VSDS) technique.
Measurements of fine-structure changing collisions such as this one are important both for comparison with recent theory and because this process is an important collision process in fine-structure lasers such as the high-power atomic iodine laser.

References

C. ELECTRIC FIELD IONIZATION RATES OF SELECTED STARK STATES IN SODIUM

Joint Services Electronics Program (Contract DAAB07-75-C-1346)

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We have undertaken to study electric field ionization by tunneling in Rydberg states of sodium, n = 12-15. We have studied the $|m| = 2$ states, which are well described by hydrogenic theory. The theory of ionization by tunneling has been developed by several workers. In particular, Bailey, Hiskes, and Riviere have calculated rates for states up to $n = 25$. Early spectroscopic observations for low levels ($n < 6$) are in agreement with theory. Field ionization studies for statistical population distributions of Stark states with larger values of $n$ have been carried out, but to our knowledge there have been no direct measurements of spontaneous ionization rates from selected Stark sublevels. Using pulsed excitation, we have observed ionization of atoms in a beam. The apparatus has been described elsewhere. Ionization rates were measured by direct observation of ion current vs time and in some instances by observation of level broadening.

The lowest level in each manifold ionizes at a rate that is in general agreement with the results of Bailey et al. For many levels, however, we find striking disagreement. Their theory predicts that ionization rates increase with field in a rapid monotonic fashion and the redder states of a given manifold (i.e., those farthest from the ionization limit) ionize first as the field is increased. We find that the bluer components ionize first, the rates for these states are not monotonic, and the onset of ionization occurs at fields that in some cases are a factor of 2-3 smaller than predicted.

The anomalous ionization phenomena appear to be due to interactions with higher lying terms. The essential mechanism is as follows: numerous level anticrossings can occur before the level of interest ionizes according to the theory of Bailey et al. If the anticrossing occurs with a level from a higher term with a large ionization rate, then the level of interest will also ionize because of level mixing. Data exhibiting these
phonenomena are shown in Fig. IV-3.

Excitation curves obtained by scanning a pulsed dye laser for increasing electric fields constitute the data. Energy is measured from the ionization limit. The signal is generated by ions collected following a 200-ns delay after excitation. The disappearance of a signal indicates that the lifetime of the level has fallen below 200 ns because of ionization by tunneling. In regions of long tunneling lifetimes, the signal is due primarily to a small amount of collisional ionization. In Fig. IV-3 the straight lines indicate the positions of levels with $|m| = 2$. These levels are essentially hydrogenic and are labeled with the parabolic quantum numbers $(n, n_1, n_2, m)$. Unlabeled peaks are due to the $|m| = 0$ and 1 levels. "A" indicates where the long-lived state $(12, 6, 3, 2)$ quenches because of mixing with the short-lived state $(14, 0, 11, 2)$. Quenching phenomena of this type, which can lead to violation of the "no crossing" theorem, have been described by Lamb. "B" indicates where the long-lived state $(12, 7, 2, 2)$ ionizes at $25$ kV/cm because of mixing with very broad $n = 15$ levels; the result essentially is premature ionization. In the absence of level mixing, state $(12, 7, 2, 2)$ would disappear at $<25$ kV/cm.

References


