Vleck's retiring presidential address at the Cambridge meeting of the American Physical Society, January 23, 1953

TWO BARRIER PHENOMENA

By J. H. Van Vleck

IN SEARCHING for a subject for this talk, I find that some addresses of retiring presidents have been discussions of topics relating to the social responsibilities and problems of physicists, while others have been technical reviews of research in a particular phase of physics. Professor Bridgman struck a compromise by giving a retiring address which was part political, part physical, and, being from Harvard, I have naturally decided to follow his pattern. One of the barriers about which I shall speak today is political and macroscopic, the other is physical and microscopic. As you perhaps have guessed, the political barrier phenomenon of which I will speak is that presented by the present policy of the United States regarding visas for visiting physicists from abroad. Because of limitations of time, I shall not discuss the reciprocal problem of the difficulties sometimes experienced by United States citizens in obtaining passports.

At the St. Louis Meeting (November, 1952) the Council of the American Physical Society adopted a formal statement which I shall now quote:

"In the past few years, the progress of American physics has been impeded by United States visa and passport restrictions. A few American scientists have been denied passports and many distinguished foreign scientists have failed to receive United States visas even for short visits to attend scientific meetings. Other foreign scientists fail to come because their visas arrive too late after delays of many months or because they had been irritated by inappropriate questionnaires and inquisitorial personal interrogations. The international notoriety of these difficulties is now such that some international scientific meetings that originally were to be held in the United States are transferred to other countries.

"The personal exchange of ideas and the collaboration with foreign scientists are essential sources of information and ideas which cannot be replaced by written correspondence or by the study of foreign publications. The present restrictions of personal contacts are cutting deeply into this important source of our scientific production. The loss of scientific potential may even jeopardize our national security. Had similar regulations been in force prior to 1942, it is questionable if the United States would have developed the atomic bomb during the last war or have made great advances in radar.

"This loss to the United States is not compensated by any gain in the security of classified information, since the meetings from which the visitors are excluded are open scientific meetings on unrestricted subjects. The main reliance for the security of our technical secrets must necessarily be on the very strict guarding of restricted information by those who have access to it and not on such illusory and ineffective procedures as the exclusion of foreign visitors from open scientific meetings. Furthermore, the interrogations of foreign scientists are chiefly effective in excluding and humiliating scientists who believe in political and intellectual freedom rather than in detecting spies, who would be less scrupulous about their answers.

"The Council of the American Physical Society is not questioning the propriety of excluding any person who seeks admission to this country with any idea of advancing communism here. However, the Council strongly urges a more realistic approach by our government to the problem of travel restrictions, to the end that free scientific interchange shall not be impeded."

The Council released this statement only after considerable reflection and soul-searching. The American Physical Society is a nonpolitical organization. The position which the Council has taken hence does not relate to political or social concepts of what American policy should be, and is confined to issues which concern our output and efficiency as physicists. As you can see from the text, the Council feels that things have reached an impasse where our professional efficacy is being seriously hampered. No doubt most of you already know of individual instances where entree has been refused some European physicist with whom you would welcome professional contacts. If not, you have only to read the October 1952 issue of the *Bulletin of the Atomic Scientists*, where you will find cases documented in detail. All told, it is a shocking and depressing record which I recommend that you examine.

I want now to add some of my personal views on the visa question, as an American citizen and individual physicist, entering into somewhat more general considerations which lie beyond the province of proper council action.

It seems axiomatic that the aim of our visa policy should be to help make America strong and secure, and I propose to look at the question solely from the selfish standpoint of our national interests. From a more altruistic standpoint, however, it seems perfectly clear that we cannot have a free world without a free America. Conversely, without the support and sympathy of Europe, the task of defending America is much more difficult, if not impossible. This is made very clear, for

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instance, by President Eisenhower's inaugural address. Let us for the moment leave aside the question of scientific research, and look at considerations that apply to philosophers, artists, business men, laborers, as well as physicists. In my opinion a less wooden and more understanding policy on visitors' visas would materially strengthen our security because of the better understanding it would provide abroad of the American way of life.

During World War II, I remember reading in the papers how American troops had just captured a small town in southern Italy or Sicily, and the American officer in command was asked by the local Italian magistrates what radio stations the inhabitants would be allowed to listen to. The answer was, "Whatever ones you feel like." A radio was set up in the market place, to the joy of the inhabitants, and probably this procedure did more to combat totalitarianism than any attempt dictatorially to tune out subversive programs would possibly have done. The American officer in charge took the traditional American approach. Our present visa policy operates too much on another philosophy, one of fear, at variance with American tradition.

Think of the bureaucracy we could have set up if after the Civil War we tried to keep all Southerners suspected of supporting states-rightism from crossing the Mason-Dixon line, or if still earlier, after the Revolution and in the midst of the monarchial controversies of Europe, we tried to exclude as visitors from our shores all those not yet indoctrinated in the American philosophy. We were in danger in those days, too—so weak the British were able to burn the nation's capitol in 1814—and a better case could perhaps be made for tight screening then than now. For a brief two year period, to be sure, beginning in 1798, we did have just that in the Alien and Sedition Laws, which were repudiated in 1800 and which caused the downfall of the Federalist Party; the hysteria which led to the passage of these short-lived laws is in many ways reminiscent of the present times. We have spent billions on the Marshall plan, and then alienate much of the resulting good will by an unsympathetically and woodenly administered visa policy. This situation reminds one of the railroad that lavishes a mint of money on new streamliners and then lets the conductor insult the passengers.

It is a truism that when visa applications are either refused or almost interminably delayed even for non-communists, psychoses and misunderstanding of our motives often result. It is little wonder that Europeans are sometimes confused about our American concepts of freedom. Communist propaganda is not slow to seize on the opportunity to try to divide Europe by inflaming such irritations and misunderstandings. It has been said that the American critics who complain about the present "red tape curtain" are taking the communist party line. If so, the motivations of loyal American citizens and of communists in exposing weaknesses in governmental policy are, of course, diametrically opposite.

In contradistinction to the ill-will engendered when visas are unnecessarily refused, there is a positive asset of good-will and better understanding which is created when Europeans are allowed to visit our shores and see our civilization at first hand. I have talked with numerous visitors, and in most every case false impressions are corrected in our favor—we are neither the money-hungry imperialistic nation represented by the leftist European press nor the collection of pompous, predatory, sometimes uncouth individuals so often depicted in the movies, but rather human individuals who wish to live and let live, and who are basically friendly. As one French visitor put it, he was surprised at what he called the "bon enfant" character of Americans. We Americans need not suffer from an inferiority complex. We are not ashamed of our civilization; it is our trump card, our strongest element of propaganda, to let others see what it is like. I believe we should play our cards in the American, not the Russian way.

I shall not pursue these points further, as no doubt most scientists are in accord on them. What is to be said on the other side? First of all, it should be freely recognized that the need of security and secrecy under the conditions of modern warfare is far more important than a century ago. It is a far cry from McClellan's ill-fated attempt in the Civil War at a landing in Virginia by sea, and other details of Union strategy, which were announced in advance in the New York and Washington press, to the secrecy attendant to the landings on D Day, whose security, incidentally, seems to me a great tribute to all concerned. Secret information in the hands of the enemy can do inestimable harm. "Atomic spy" is a catch-word of the popular press. However, it does not seem to be objectively and scientifically analyzed what security risk is associated with the casual visitor to our country. Is he going to take back secret information even though he is not admitted to classified areas? Is the danger of the saboteur type? Or is it the fear that these visitors would inspire our leftist organizations to be more radical or more effective? These various considerations should be weighed objectively against the other angles I have mentioned and the balance examined in a hard-boiled way as to how we are most likely to secure peace and security rather than invoking vague, emotional appeals as to the dangers of communism. On one point I want to be clear—our classified information must be zealously guarded. There is danger that we be diverted from this if we dissipate our efforts at security on the trivial rather than on the important. For example, we fingerprint both the tourist and the classified worker. The moment we start guarding our toothbrushes and diamond rings with equal zeal, we usually lose fewer toothbrushes but more diamond rings.

It is, of course, because of the horrors of modern atomic warfare that the man in the streets is so concerned about questions of security. I have the feeling that physicists are inclined to overlook the very real worry of the average person about the present danger and attribute all difficulties to a few politicians. Politicians, however, by and large reflect the tempo of the people, many of whom, when queried, would no doubt endorse the present visa policy because, as they would say, "we don't want communists snooping around, especially if they're physicists". Obviously more thought is needed about the more subtle pros and cons of the situation as it actually exists and what procedure in the long run makes us the most secure. I do not mean for one moment to question the propriety of denying admission to known communist agitators and trouble makers, but I am concerned over the exclusion of many individuals who are instead basically our friends.

Possibly you may react that all this is of too general a scope to be proper material for an address to the Physical Society rather than a general audience. However, with the augmented role of science in national defense, the physicist finds himself in a position of unusual influence at the present time. It is a recognition of his importance that visa applications of physicists are subject to special scrutiny, and as a result the barrier problem is a particularly acute one for us.

What can we do to improve the situation? It seems to me that the following points can be stressed.

1. In our human contacts and in our daily walks of life, use our influence to see that the basic facts are known, and the issues regarded objectively and unemotionally.

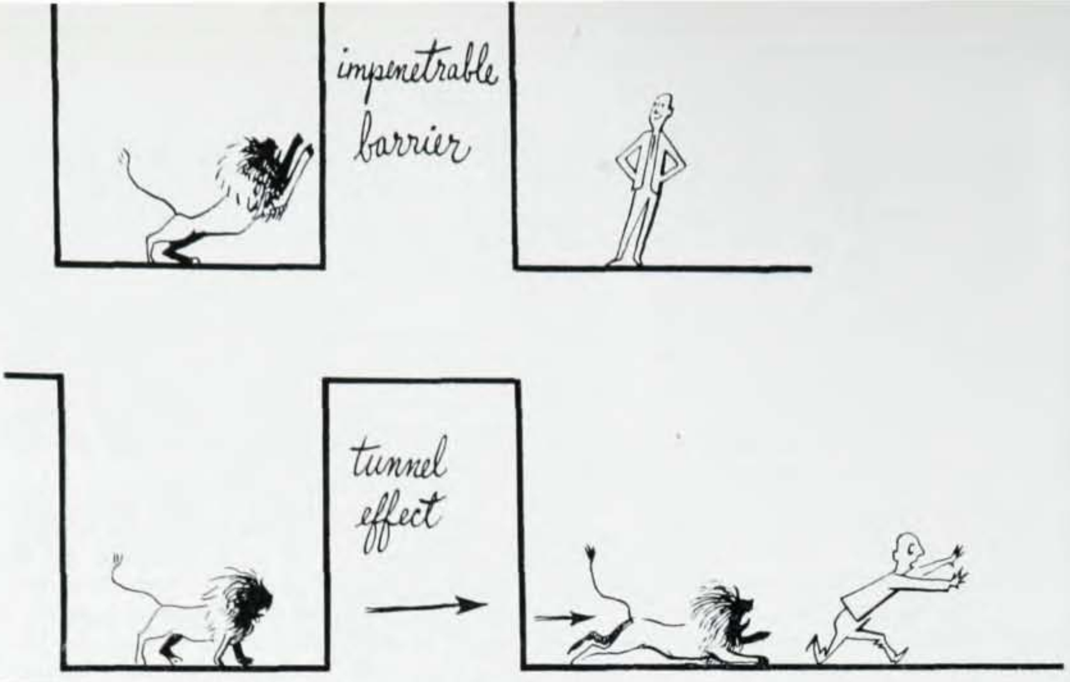
2. Urge our European visitors to apply well in advance for visas, and do what we legitimately can to help them. Oftentimes the trouble comes mainly from delay or poor presentation.

3. Do all we can to keep our own house in order. It is a disgrace that we have had the names of Fuchs, May, and Pontecorvo among physicists, and we might as well face this fact candidly. The list of physicist traitors is small, but the damage which they can do is very great. We must bend every effort to see that such cases do not arise again. The task is not easy—a professional spy cannot be uprooted merely by a front page offensive against communism. As I have already said, physicists are at present in a rather focal spot, and for that reason it is important that our conduct be impeccable. "Caesar's wife must be above suspicion." Refusal to testify, granted it is a constitutional right, and unwillingness to state where one stands, are not calculated to win public confidence.

4. Do what we can in pressing for more sympathetic legislation, and for a more rational and mature administration and interpretation of what legislation we do have. I shall not attempt to go into the problem of how much of the present impasse is the fault of legislation and how much of administration. On reading the McCarran Act, I do form the impression that certainly most of our difficulties would not have arisen if it were administered as broadly as the gold clause of our currency legislation was interpreted by the Supreme Court during the depression. Just plain bad judgment and inefficiency are often to blame in many instances where visas have been refused. Many cases, in fact, can be cited where even under the narrowest interpretation of the law entry should have been permitted. It is indeed ironical that Polanyi, perhaps the most outspoken foe of the communistic mode of thought among all physicists or chemists, should be denied the opportunity for visiting America even temporarily, whereas Fuchs was cleared for our most vital secrets.

THE OTHER BARRIER PHENOMENON of which I will speak is the potential barrier involved in the so-called inversion spectrum of ammonia. I choose this for my second topic because the progressive unravelling of the ammonia spectrum furnishes a vivid case history of how microwave spectroscopy has developed in the last two decades.

The inversion spectrum of ammonia is located at a wave-length of about a centimeter and a quarter and arises from the peculiar tunnel effect in quantum mechanics which permits the molecule to turn itself inside out. The ammonia, or NH_3, molecule has a pyramidal structure with two alternative forms which differ from each other merely by an inversion. The three hydrogen atoms are located at the three corners of the base, whose plane we shall consider to be horizontal. One possibility is that the nitrogen atom be above this horizontal plane, the other that it be below it—in other words the apex of the pyramid may point either upwards or downwards. One configuration can be obtained from the other by turning the molecule inside out. However, to do this the molecule must be squashed as the intermediate stage in the inversion of the pyramid. The intermediate, pancake configuration has a high potential energy, more than the total energy available, and classically the molecule would have to stay in one form or the other; for in the intermediate configuration, the kinetic energy $\frac{1}{2}mv^2$ would be negative, and it does not make sense to talk about an imaginary velocity. In quantum mechanics, on the other hand, there is a finite probability that a particle can penetrate into classically forbidden regions, pass through the barrier, and appear on the other side. Any such process is, of course, contrary to one's physical intuition founded on what happens in ordinary, large scale mechanics. One's basic sense of security is founded on the idea that if one has, say, a lion and a protecting wall to surmount which requires more energy than the lion possesses, there is no chance of the lion appearing on the other side of the wall. With quantum mechanics, however, there is a finite probability that the lion will penetrate the barrier and somehow appear on the other side (cf. Fig. 1), a rather disagreeable prospect to contemplate. This is my second barrier phenomenon. Of course from the classical viewpoint this seems like nonsense, but quantum mechanics is essentially a wave mechanics, and mathematically the effect is comparable with the fact that in physical optics light can penetrate the geometric shadow, a phenomenon which would be completely incomprehensible to someone who understood only geometrical optics. The reason



Classical Mechanics

Quantum Mechanics

Fig. 1

that we do not observe the tunnel effect with ordinary objects is that the probability of penetration decreases in a rapid exponential fashion with the mass of the object, and the mass of the lion is some thirty ciphers too big to give any appreciable probability of penetration. So there is no need to worry the next time you visit a zoo.

On the other hand, the hydrogen atoms in ammonia are so light that there is a real probability of the barrier being penetrated and the molecule turning itself inside out. In Fig. 2, one valley corresponds to one configuration of the molecule, and one to another. The molecule is continually turning itself inside out, resonating from one valley to the other. In terms of energy levels, it can be shown from quantum mechanics that instead of there being two levels of equal height, each in its own valley, there are two levels of slightly different height, in both of which the molecule divides its time equally between either valley. Analytically, the distinction between the two states is that their wave functions are respectively even or odd as regards reflection in the origin. The difference between these two energy levels when divided by h is the characteristic frequency of the inversion line of the ammonia spectrum, and is essentially the frequency with which the ammonia molecule is turning itself inside out.

The upper pair of levels in Fig. 2 represents a higher vibrational state for which the potential barrier is less and the spread of the levels hence is greater. Transitions between the upper and lower pairs of levels shown in Fig. 2 give radiation in the ordinary infrared region, and the structure due to the tunnel effect was first detected as a frequency difference between two lines in

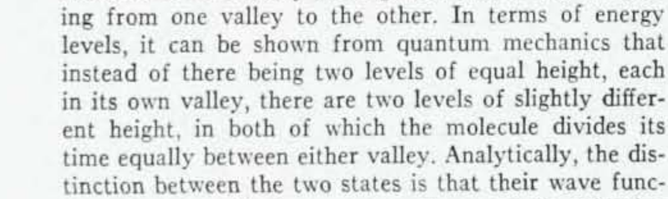


Fig. 2

the vibrational spectrum of ammonia. However, the transition between the two fundamental levels has subsequently been detected directly by means of microwave techniques. The separation between these levels is, incidentally, wide enough to be observable only if the molecule is composed of light atoms, and this is why the experimental observation of inversion lines is so far confined to ammonia. For complicated organic molecules, the effective mass is so great that the inversion frequencies amount to days or even years, so that the separation of the levels is negligible. For this reason chemists are able to prepare isomers, which correspond quantum mechanically to wave packets in which the molecule is definitely in one valley or the other, and furthermore to keep them in bottles for years. In principle, the molecule should de-isomerize itself by turning inside out, but the probability is so low that to all intents and purposes this doesn't happen, any more than the lion penetrating the barrier.

Because ammonia is unusual in having its inversion frequency in the microwave region, it absorbs microwaves far more intensely than any other common gas. The astronomers tell us that the atmosphere of Jupiter is mainly ammonia. If somehow one were to live on Jupiter, one can be assured that there could be no radar there, for the radar waves would be attenuated in a very short path length. Other molecules may have a particular rotational line in the microwave region, but in ammonia the entire inversion spectrum falls in the microwave region, regardless of the rotational state. During the war, when some physicists at the Radiation Laboratory were vainly hunting for the microwave spectrum of water, I suggested that they see if the apparatus was working by putting in a little ammonia. They thus found that indeed it was, but they had practically to abandon the apparatus because they could never get rid of the effect of traces of ammonia.

As early as 1932, the existence of the ammonia inversion line had been inferred from combination differences in the infrared and theoretical studies by Den-

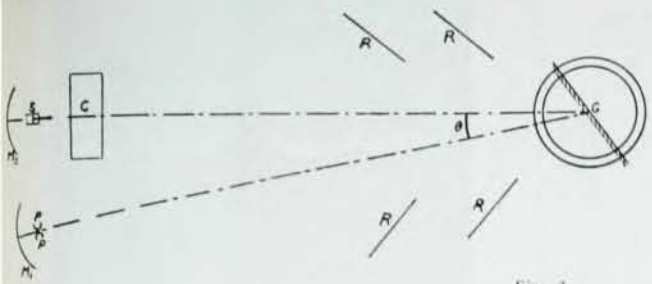


Fig. 3

nison and Uhlenbeck, as well as by Morse and Rosen. It was first directly detected in some "prehistoric" experiments made by Cleeton and Williams in 1934 at Michigan before the advent of war and radar. The apparatus was comparatively primitive, as shown schematically in Fig. 3. The source of the microwaves was a magnetron. Usually one thinks of a grating as something with rulings so close that one cannot see them with the naked eye. However, since the wave-length of our ammonia line is about half an inch, Cleeton and Williams could use for a grating a piece of corrugated metal that I like to characterize as a child's washboard but which my colleague, E. Bright Wilson, terms more aptly a Venetian blind, since the inclination of the blades can be made variable so that the angle of incidence equals the angle of reflection. One detects the absorption by ammonia simply by finding out whether or not less radiation reaches the bolometer when a rubber bag filled with ammonia (labelled C in Fig. 3) is inserted in the path.

A picture of typical, modern post-war apparatus for studying the absorption in the microwave region is shown in Fig. 4. It is obviously much more elaborate, and is based on the transmission of microwaves by wave guides. Some twenty feet of wave guide are coiled up in this particular apparatus—what one does is essentially to study the difference in transmission of the wave guide when it is empty and filled with gas.

Because of the improvement in technique, one obviously expects, and finds, much better resolution of the ammonia line with the modern apparatus than with the 1934 version. Fig. 5 shows how the profile of the line looked back in 1934. Here the dispersion is so low and the spectrum is so blurred that the spread of the line is comparable with the central frequency. Fig. 6 shows what was obtained ten years later. The spread in frequency in Fig. 6 is about 2000 megacycles, or some ten percent of the proper frequency of the line. Notice that the line has a fine structure or, in other words, consists of a number of components. This is because different molecules have different amounts of rotation or, in more technical terms, different rotational quantum numbers J, K. Different amounts of centrifugal force make the potential barriers, and hence the tunnel frequencies, slightly different for fast than for slowly rotating molecules. The values of J, K are listed as "line designations" in Fig. 6. A typical theoretical formula for the dependence of the tunnel frequency on the rotational quantum numbers J, K is given in Eq. (1), which is included merely to exhibit the complexity and refinement of the analysis.

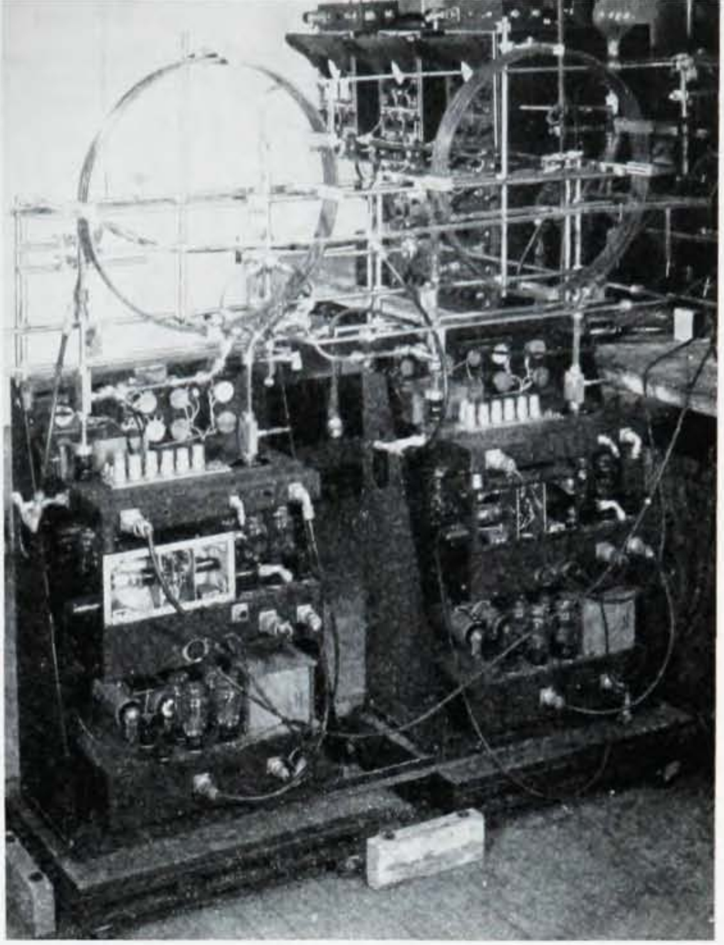


Fig. 4

$$\begin{aligned}\nu = {} & 23{,}785.8 - 151.450J(J+1) + 211.342K^2 \\ & + 0.503027J^2(J+1)^2 - 1.38538J(J+1)K^2 \\ & + 0.949155K^4 - 0.001259997J^3(J+1)^3 \\ & + 0.005182367J^2(J+1)^2K^2 \\ & - 0.007088534J(J+1)K^4 + 0.003210437K^6\end{aligned} \qquad (1)$$

In this connection, it should be particularly emphasized that microwave is vastly superior to old-fashioned optical spectroscopy because the fine structure is an appreciable fraction of the microwave frequency.

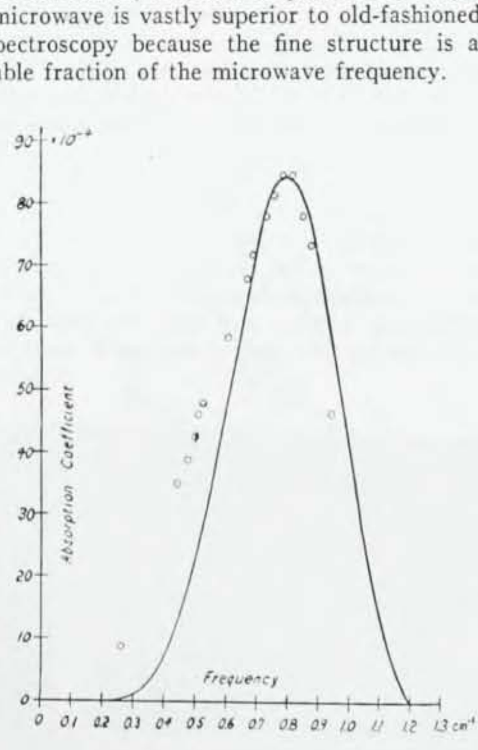


Fig. 5

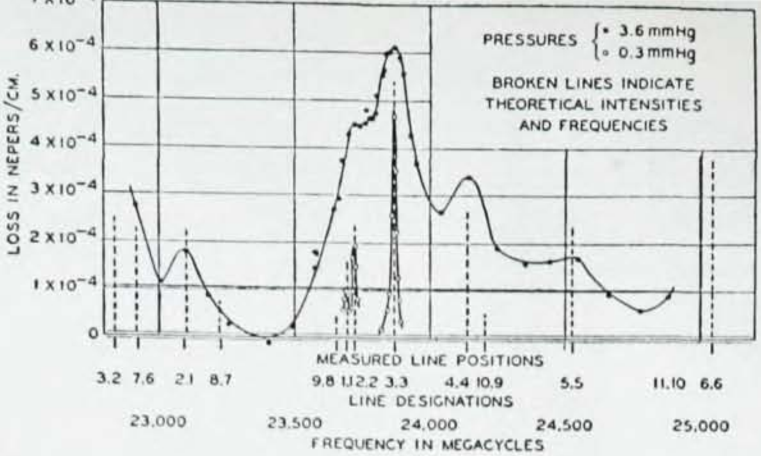


Fig. 6

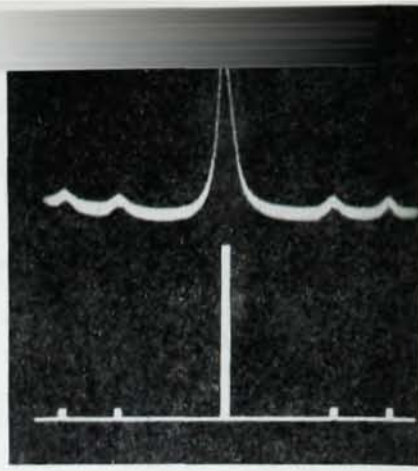


Fig. 7 ($J=2$, $K=2$)

The dispersion can be made even greater than in Fig. 6 by using oscilloscope sweep techniques. When this is done, each rotational component appearing in Fig. 6 usually separates into five subcomponents. Fig. 7 shows this hyperfine structure for one of the rotational lines. The total frequency band covered in Fig. 7 is only two or three megacycles, or approximately 1/10,000 of the proper frequency. The occurrence of additional splittings of the lines as the dispersion increases suggests an old quotation of Jonathan Swift, as follows:

> "So naturalists observe
> A flea has smaller fleas than on him prey,
> And these have smaller still to bite 'em
> And so proceed ad infinitum".

My connection with the ammonia problem is entirely in the flea or hyperfine effects, as in this aspect I have collaborated in the interpretation of results obtained with improved dispersion at three different stages. When hyperfine structures such as those shown in Fig. 7 were detected in some experiments made by Daley, Strandberg, and Kyhl at the Massachusetts Institute of Technology, Professor E. Bright Wilson asked me to examine what the fine structure would be like if due to the quadrupole moment of the nitrogen nucleus. I telephoned the formula to Wilson, who relayed it by telephone to MIT, and additional measurements testing the formula were immediately undertaken. The result was, of course, a letter to the editor. A few years later, I had the pleasure of meeting some of the men who were my collaborators in this letter. I should mention that at Westinghouse, Coles and Good obtained similar results, both experimentally and theoretically, and at Iowa, Jauch also independently developed the theory.

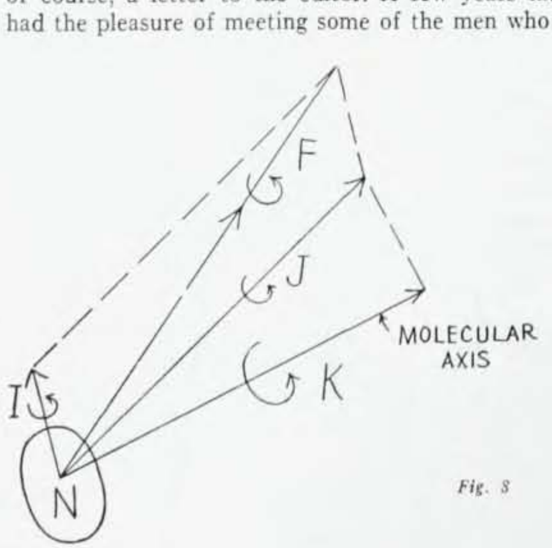


Fig. 8

Different orientations of the nuclear spin I relative to the molecular frame are characterized by different values of the fine quantum number F. The compounding of the various angular momentum vectors is illustrated in Fig. 8. The spin I of the nitrogen nucleus is unity, and so the possible values of F are $J-1$, J, and $J+1$. The theoretical formulas for the frequency differences between the central line and each of the four satellites are

$$h\Delta\nu = \pm\frac{3}{8}eQ\frac{\partial^2 V}{\partial z^2}\,\frac{J+1}{2J+3}\left[1-\frac{3K^2}{J(J+1)}\right],$$
$$h\Delta\nu' = \pm\frac{3}{8}eQ\frac{\partial^2 V}{\partial z^2}\,\frac{J}{2J-1}\left[1-\frac{3K^2}{J(J+1)}\right], \qquad (2)$$

where Q is the quadrupole moment of the nitrogen nucleus defined in the standard Columbia fashion. V is the electrostatic potential at the nitrogen nucleus arising from the charges outside that nucleus, and the z axis is that of symmetry. The predicted and observed pattern agrees quite well, as Table 1 shows.

Table 1. **Calculated and Observed Ratios of Satellite Displacements.**

JK	$\Delta\nu_{JK}/\Delta\nu_{11}$ obs.	calc.	$\Delta\nu'_{JK}/\Delta\nu'_{11}$ obs.	calc.	$\Delta\nu'_{JK}/\Delta\nu_{JK}$ obs.	calc.
11	($\Delta\nu_{11,obs}=0.60$ mc)				2.62	2.50
22	2.17	2.14	1.31	1.33	1.58	1.56
33	2.87	2.78	1.49	1.50	1.36	1.35
44	3.18	3.18	1.58	1.60	1.30	1.26

A particularly interesting arithmetical consequence of the theory is that the satellites should disappear when $J=3$, $K=2$, as then the factor $1-[3K^2/J(J+1)]$ in the equations (2) vanishes. It is indeed found experimentally that the hyperfine structure is missing for the line $J=3$, $K=2$. The hyperfine structure should also be, and is, wanting when $N^{15}H_3$ rather than $N^{14}H_3$ is measured, as the spin of the N^{15} nucleus is $I=\frac{1}{2}$, for which no quadrupole moment is possible.

When more precise measurements of the microwave pattern were made, notably by Smith and Gordy at Duke, it finally became apparent that there were perceptible deviations from the relative intervals predicted by the quadrupole interaction. However, one must not forget that the nitrogen nucleus has a magnetic dipole moment. The effect of this is to add to the Hamiltonian a small extra term of the structure

$$\left[a+\frac{bK^2}{J(J+1)}\right][F(F+1)-J(J+1)-I(I+1)], \quad (3)$$

Inclusion of this term materially improves the agreement with experiment, as is shown by Table 2, which is taken from a paper by Henderson.

Table 2

Discrepancies (kc/sec.)

		in $\Delta\nu$		in $\Delta\nu'$	
J	K	New	Old	New	Old
1	1	−6	+3	+9	−6
2	2	+12	+25	+1	−24
3	3	+1	+17	0	−32
4	4	+13	+36	0	−40
5	5	+15	+43	−17	−63
6	6	+10	+42	−6	−63
7	7	−12	+28	−19	−80
8	8	−3	+42	−6	−75
9	9	−17	+34	+17	−58
2	1	−11	+10	−8	−15
4	3	−7	+22	−2	−30
5	4	−13	+20	+2	−34
6	5	−8	+30	+3	−43
7	6	−15	+28	+6	−47
4	2			−22	−43

The words "old" and "new" in Table 2 mean that the calculations are respectively exclusive and inclusive of the magnetic term (3). The word "new" is, however, in a certain sense a misnomer, as Table 2 was prepared in 1948. In a recent experimental and theoretical analysis made at Columbia in 1952, Gunther-Mohr finds that with proper adjustment of the constants the deviations can be reduced still further, so that they are only a quarter or so as great as in the "new" columns of Table 2. Part of the improvement which he obtains is due to the inclusion of the influence of centrifugal expansion on the quadrupolar coupling, obviously a high order effect.

Now for the last wrinkle in the hyperfine structure of ammonia. This is the inclusion of the spin of the hydrogen nuclei, which we have previously neglected, and

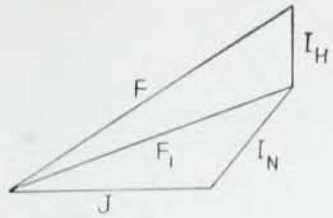


Fig. 9

which superposes an additional quantum number, as shown in Fig. 9. Here I_H is the collective spin of the hydrogen nuclei, which has solely the value $\frac{1}{2}$ because of restrictions imposed by the Pauli exclusion principle. It is customary to use the letter F for the quantum number associated with the molecule's total angular momentum, including all sources, and so F_1, I_N in Fig. 9 are the same as F, I in the previous notation used in Fig. 8 and in Equations (2) and (3), which neglected I_H.

The most noticeable effect of the spin of the hydrogen nuclei, in fact the only effect so far detected, is an extra splitting of the states having $K=1$. We omit the theoretical formulae, as they are quite complicated.

As early as 1949, Coles of Westinghouse had suspected that the levels $|K|=1$ had a doubling in addition to the hyperfine structure associated with the quadrupole moment of the nitrogen nucleus. This suspicion has been confirmed in subsequent measurements both at Westinghouse and Columbia. In 1950, Townes raised the question with the writer whether the interaction of the spin of the hydrogen nuclei with the molecular rotation might not lift the degeneracy of the states $K=\pm 1$, thereby giving the doubling. I verified that theoretically this is indeed the case. The theory and experiment have subsequently been refined by Gunther-Mohr at Columbia. Fig. 10 shows the doubling for the state $J=3$, $K=1$, to be contrasted with Fig. 7, where $K>1$ and the doubling is missing. Space will not permit an elaborate comparison between theory and experiment, but it can safely be said that the theoretical predictions are in nice accord with experiment. For instance, the theory predicts that the higher peak of the doublet for the main component be alternately on the low and high frequency side as consecutive values are assigned to J. In Fig. 10 ($J=3$) the higher intensity component is on the right. On the other hand, for $J=4$ it is on the left, as shown in Fig. 11, which includes only the main or center line.

Besides the doubling of the states $|K|=1$, the interaction of the spin of the hydrogen nuclei with the molecular rotation should also have the effect of adding certain closely spaced satellite structures in the case of other lines. Existing dispersion is insufficient to resolve these satellites but they may well be detected before 1953 is over. When this is done, the last flea will have been caught.

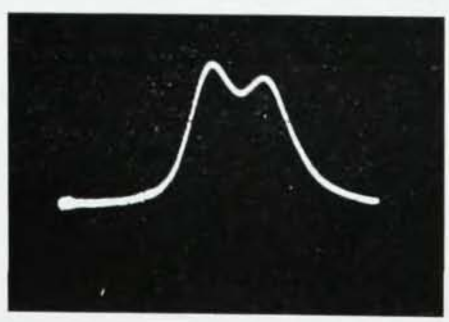


Fig. 11 (center of $J=4$, $K=1$)