INTRODUCTION

Professor Isadore Rudnick became interested in measuring attenuation in metals at low temperatures shortly after Bommel in 1954 (1) discovered spectacular ultrasonic effects in a crystal of lead. Bommel found that the attenuation in Pb increased when its temperature was decreased below 10K. This effect was unexpected, since most interaction mechanisms were expected to vanish at low temperatures. Furthermore, the attenuation decreased almost exponentially below the superconducting transition of Pb, another surprising result. Feverish theoretical activity followed these discoveries. By the time BCS (2) published their seminal theory of superconductivity in 1957, it was well accepted that these effects were due to electron-phonon interaction between sound waves and the conducting electrons in the metal. BCS derived an elegant theoretical result for the ratio of the attenuation in the superconducting state to that in the normal state at the same temperature in terms of an exponential function of the superconducting energy gap $\Delta$: $2 / (1 + \exp (\Delta/ kT ))$, where $k$ is Boltzmann’s constant and $T$ is the absolute temperature. The energy gap is the energy per electron required to break up a Cooper pair of electrons. BCS also derived a functional relation for the temperature dependence of $\Delta$. The ultrasonic measurements provided one of the fundamental experimental facts that verified the BCS theory.

Seven of the thirty-two PhD students supervised by Izzy studied electron-phonon interaction and superconductivity in metals. Their names follow in chronological order: Daniel Filson, Edward Lax, John L Brewster, Moises Levy, Richard Stern, Reynold S. Kagiwada, and Giuseppe Natale.

METALS AND PHASE TRANSITIONS

Izzy realized that there were two research areas that were opened up by Bommel's measurements. The first was to determine the relation of the number of free electrons in a metal to the absolute value of the attenuation due to electron-phonon interaction. The other was to determine the validity of the BCS relation for various superconducting metals. He first started a program of measuring electron-phonon interaction in aluminum and silver using Young's modulus waves. Dan Filson used a pulse echo technique on Al cylindrical rods, while Ed Lax used a decaying resonance technique on Al and Ag rods. They found that their experimental results agreed exactly with both the frequency and temperature dependence predicted by the theoretical models. However, the absolute experimental attenuation values were less than twice as large as the theoretical ones. Since both Al and Ag have complex Fermi surfaces, Izzy decided to measure sodium and potassium, since these should have close to spherical Fermi surfaces. Dick Stern measured Na and Giuseppe Natale measured K and, also, gold. Both used a technique similar to that of Filson's. Here is where Izzy and his students demonstrated their experimental ingenuity. They discovered that these samples had to be extruded at liquid nitrogen temperatures and not allowed to warm above these temperatures in order to obtain small crystalline grains that were not preferentially oriented and which were small enough not to produce significant Rayleigh scattering of the Young's modulus waves. Therefore, the acoustic bonds between the transducers and the specimens had to be made at liquid N temperatures once the specimens were extruded. They successfully developed experimental techniques to accomplish this. However, sodium undergoes a Martensitic transformation at low temperatures and potassium exhibits dislocation motion at low temperatures and so does gold. Therefore,
only a qualitative determination of electron-phonon interaction could be determined. They did discover a new metastable state of sodium, and dislocation motion in K and Au.

SUPERCONDUCTORS

Once the electron-phonon interaction measurements were underway, Izzy and John Brewster initiated pulse echo ultrasonic measurements in superconducting vanadium up to 500 MHz. As was Izzy's modus operandi, before John finished his experiments, Izzy asked John to train me, and in a similar fashion Reynold Kagiwada followed me. We verified the BCS relation for vanadium, niobium and tantalum for both longitudinal and transverse waves in the case when the electron mean free path is smaller than the sound wavelength. This was a new result for the shear waves. By the time Reynold joined the group, type II superconductors had been generally recognized. We discovered that, in pure type II superconductors close to the upper critical magnetic field, the attenuation of sound waves depended on the square root of the difference between the critical field and the applied magnetic field. According to Maki [3], this was because in pure type II superconductors, the interacting electrons sample the space average of the order parameter, which is proportional to this square root.

DISCUSSION

By 1960, Izzy was dividing his time equally between work on metals and work on superfluid helium. He and Kenneth Shapiro discovered Fourth Sound experimentally in 1962 (4). By 1968, Izzy had decided that work on superfluid He was more attractive, particularly since then he wouldn't be beholden to anyone for samples. And, after all, both superconductors and superfluids were the only known examples of macroscopic systems that exhibited quantum mechanical properties.

Now, I would like to turn to some personal reminiscences. Izzy was very concerned with our well being throughout our careers, particularly as graduate students. He would visit our labs often in the afternoons to encourage us and keep tabs on our progress. When we were stuck, he would make insightful suggestions, "Moises, look at your failing bonds under a microscope". He would spend long nights with us, especially during the difficult times of acquiring experimental data for the first time, so that he could help us recognize significant effects before they disappeared. During these periods, he would emphasize, by example, the necessity of extracting the maximum amount of data when all systems were working; and, when needed, he would remind us that the acquisition of data required our presence, such as the time he wrote on our blackboard "I was here at 7, 8, 9, 10, and 11 pm. Where were you [Moises and Kenneth]?" He introduced us to all the famous visitors, sometimes bringing them down to the labs. This is how I came to use epoxy to make ultrasonic bonds for use at low temperatures; and, how I spent a year as a post doc in Olsen's lab in Zurich, Switzerland.

Izzy was an ideal mentor and a true friend throughout my professional career. I think my sentiments are shared by most of Izzy's PhD students.

REFERENCES