but especially of such an exquisitely sensitive measurement as testing for trace elements.

Velmer A. Fassel, a chemist at Ames Laboratory (concurrent with Stanley Greenfield in the United Kingdom), wondered whether it would be possible to develop a satisfactory *electrical* flame—a plasma—to start off the spectroscopic analysis. This would be a way to get an even hotter gas to tear the molecules apart and excite the free atoms and ions without the contamination of combustion or electrode materials.

Fassel's method for heating the sample came not from chemistry, but from physics. Such a cross-fertilization is not surprising in the environment of a multidisciplinary laboratory. At the heart of an inductively coupled plasma device, argon gas flows continuously through the core of a copper coil carrying an electric current. Here the electricity flowing through the coil creates an alternating magnetic field that induces an electric current to flow through the gas. This then heats the argon to such high temperatures, 10,000°C, that it becomes ionized and forms a plasma. In scientific jargon, the electricity in the coil is *inductively coupled* to the plasma.

A liquid aerosol from material to be analyzed is sprayed into the argon plasma. The intense heat of the plasma evaporates the solvent and vaporizes all of the chemicals in the sample. As the sample rapidly becomes even hotter, the molecules of the sample separate into fragments and individual atoms, electrons are stripped from many of these and raised to different orbits in others, thus transforming them into excited ions and excited atoms.

Because argon is an inert gas and will not react with the elements in the sample, the materials being analyzed can remain in the plasma longer and be heated even hotter. Once the materials from the sample are heated in this manner, they are ready to be fed to light, mass, or other types of spectroscopic devices to have their elemental content identified and quantified.

Higher temperatures, a less active chemical environment, and operation at atmospheric pressures lead to vast improvements in test material formation and excitation and allow precise control of movement of the test material to the spectroscope. The argon plasma can be sustained under low power conditions that are safer and more comfortable for analytical chemists, while sample material is handled in the convenient form of liquid aerosols.

Having solved the problem of how to prepare the sample material, Fassel and his team turned their attention to wedding their inductively coupled plasmas to light and mass spectrometers. Optimizing the design parameters of the plasma and making the electronics of the spectrometers compatible with the plasma were difficult tasks. It would take more than a decade to develop practical instruments.

The first new approach, and the goal of the original research, emerged in the mid 1970's. It took the form of various laboratory instruments for *inductively coupled plasma atomic emission spectroscopy*. The approach is particularly well suited to rapidly finding many elements in a single mixture and measuring the concentration of each. Scientists call this process fast multi-elemental analysis.

Emission spectroscopy instruments analyze the light emitted directly by the hot ions and excited atoms in the sample material. A component of each instrument, called a spectrometer, separates the light of different wavelengths and measures the intensity of each. Light intensity indicates the amount of material present in the sample.

In a second approach first reported in 1979, inductively coupled plasma atomization cells were made part of *atomic fluorescence spectroscopy*. In this technique, light of a wavelength known to be absorbed by a specific element is shined into the plasma. Only the atoms of this specific element absorb this light, and they re-emit it almost immediately. The patterns and intensities of the re-emitted light, separated by a spectrometer, indicate the presence of the target element and its concentration.

Atomic fluorescence spectroscopy by its nature, provides a higher degree of selectivity in identifying trace elements because the signal from the underlying background is rejected. In the past, combustion flames had been used as a means to convert the sample into free atoms. Inductively coupled plasma brought to atomic fluorescence spectroscopy a more efficient way to generate free atoms from sample material and a greater freedom from interferences between elements in the atomization process.