The work reported in this thesis starts with the development of a linear ion trap for trapping Yb\(^+\) ions. The Yb\(^+\) ions would be laser cooled and the lifetime of low-lying metastable states would be measured, with the ultimate aim being to use laser-cooled ions for measuring signatures of discrete symmetry violations in the laws of physics.

One of the crucial requirements for laser cooling trapped ions is that the frequencies of the lasers used have to be correct. Also, the laser frequencies should be stable against temporal drifts. For this purpose, we developed some new techniques for precisely measuring and locking the frequencies of lasers. We subsequently used these techniques for high precision frequency measurements of atomic transitions in several species.

The first frequency measurement technique consists of a scanning Michelson interferometer called the wavemeter. It gives the wavelength ratio of two lasers that are made to travel the same path in the interferometer. The wavelength of the reference laser, which is a diode laser locked to the \(D_2\) line in \(^{87}\text{Rb}\), is known very accurately from previous measurements; consequently the wavelength of the unknown laser is obtained from the measured wavelength ratio. The wavelength is then converted to frequency using the refractive index of air. We used the wavemeter to measure the fine-structure interval in Rb, and the absolute frequencies of the \(D_1\) and \(D_2\) lines and fine-structure interval in K, with an uncertainty of about \(4 \times 10^{-8}\).

For the frequency locking, we developed a ring-cavity resonator that is stabilized to the \(D_2\) line in \(^{87}\text{Rb}\). A major advantage of the ring cavity over linear cavities is the absence of optical feedback that can destabilize lasers. We used our ring cavity to lock the frequency of a tunable diode laser. We were also able to scan the frequency of the
diode laser over several GHz by scanning the cavity length.

We then proceeded to use our ring-cavity resonator as a length standard to measure the absolute frequencies of atomic transitions. The cavity length is calibrated against the $D_2$ line in $^{87}\text{Rb}$, the frequency of which has been measured with an uncertainty of 10 kHz. The cavity is brought into resonance with this laser and locked to it. Then, a second laser tuned to the atomic transition of interest is coupled into the cavity. This laser, in general, would not be in resonance with the cavity. We use an acousto-optic modulator (AOM) to compensate for the frequency offset of the second laser from the cavity resonance. The AOM is then locked to this frequency difference in a feedback loop. We used this technique for absolute frequency measurements of the $D_2$ line in $^{85}\text{Rb}$, the $D_1$ line in $^{86}\text{Rb}$ and $^{87}\text{Rb}$, and the $D$ lines in $^{39}\text{K}$, with an uncertainty of $\sim 50$ kHz. We also measured the isotope shifts in the 398.8 nm line in Yb with $< 1$ MHz precision. Our measurements have improved previous measurements on these atoms by up to two orders of magnitude.

Thus, we were able to develop techniques for frequency measurement and locking of lasers which would be useful in future efforts towards laser cooling trapped ions. In addition, our measurements of hyperfine structure and isotope shifts could help in fine-tuning atomic wavefunctions used in theoretical calculations. The absolute frequency measurements of the $D$ lines in Rb and K could lead to a new high-accuracy measurement of the fine structure constant $\alpha$.

The thesis is organized as follows. In Chapter 1, we give a brief introduction to our work. In Chapter 2, we describe the linear ion trap for trapping Yb$^+$ ions. We give the linear trap theory, followed by a detailed description of the system hardware for trapping and laser-cooling Yb$^+$ ions.

In Chapter 3, we describe the wavemeter that we developed for measuring the frequencies of lasers. We first characterized the wavemeter by measuring a known frequency interval in $^{85}\text{Rb}$. We then proceeded to measure the fine-structure interval in Rb with an uncertainty of $\sim 16$ MHz. Finally, we improved the instrument and used it to measure the absolute frequencies of the $D$ lines and fine-structure interval in K with an uncertainty of $\sim 6$ MHz.
In Chapter 4, we describe our ring-cavity resonator. We analyze the resonator using the standard ABCD matrices that are used to trace the path of Gaussian beams. We give the design and construction of our ring cavity and go on to an experiment where we locked the frequency of a tunable diode laser ("slave laser") to the ring-cavity resonator that was itself stabilized to a diode laser ("master laser") locked to the D2 line in 87Rb. By scanning the master laser, we were able to scan the cavity length that in turn scanned the frequency of the slave laser locked to the cavity.

In Chapter 5, we describe our measurements of the absolute frequencies of atomic transitions using the ring-cavity. We start with frequency measurements on the D2 line in 85Rb. We give a detailed discussion of the technique, the possible sources of errors, and ways to check for the errors. In the course of these measurements, we showed that we could lock our diode lasers to line centers with an uncertainty of ~30 kHz. We then describe a set of measurements that we performed on the 398.8 nm line in Yb. We accessed the line by frequency doubling a tunable Ti:Sapphire laser using a commercial frequency doubler, and we avoided the complications associated with UV frequency measurements by measuring the IR frequency. We obtained <1 MHz precision in our measurements and were able to resolve several discrepancies in previous measurements on this line. The UV measurements were followed by measurements of the the D1 line in 85Rb, 87Rb and 39K with an uncertainty of ~50 kHz. We describe how the measurements of these lines could lead to a more accurate measurement of the fine-structure constant α. We end this chapter with the absolute frequency measurement of the D2 line in 39K. This measurement is complicated by the fact that the energy levels in the D2 line in 39K lie within a range of about 30 MHz. As a result, it is impossible to resolve individual levels using conventional saturated-absorption spectroscopy. We performed a computer simulation to extract the line center of the D2 line from the measured spectrum, which we describe in detail.

The frequency measurements for Rb and K were done using conventional saturated-absorption spectroscopy which uses counter-propagating pump and probe beams. Cross-over resonances often limit the resolution obtained in saturated-absorption spectroscopy, especially if the energy levels are closely-spaced as in the case of the D2 line in 39K.
In Chapter 6, we describe a new technique to avoid crossover resonances by using co-propagating pump and probe beams. We used this technique to measure a hyperfine interval in the $D_2$ line in $^{85}$Rb with an uncertainty of $\sim 70$ kHz. We were also able to resolve the overlapping $F = 2 \rightarrow F'$ transitions in the $D_2$ line in $^{39}$K which are separated only by $\sim 10$ MHz.

In Chapter 7, we give a broad conclusion to the work reported in this thesis and suggest future avenues of research to continue the work started here. We conclude the thesis with two brief Appendices: in Appendix A we give the C-programme that was used for the frequency measurements using the ring-cavity resonator, and in Appendix B we describe the AOM double-pass and intensity stabilization scheme used in Chapter 6.