Our main objective in this thesis was to investigate some aspects of the quantum-classical connection in various systems of interest. Inspite of quantum theory's philosophical conflicts with classical concepts, its overwhelming success has established it as the fundamental working theory of nature. The correspondence between the classical and quantum theory, however, still remains a challenging topic of research with many unresolved issues. Our goal in this thesis was to look at some systems and circumstances where the understanding of this correspondence is of prime importance.

A natural first choice was an investigation of the relationship between quantum dynamics and classicality in the context of the quantum measurement problem - an interpretational difficulty of relevance to all of physics. Of the various approaches to the problem, in this thesis we adopted the 'environment-induced-decoherence' approach. In Chapter 2 we applied this approach to study measurement on a spin-1/2 system via two different apparatus models. Our analysis sheds some light on the nature of the apparatus that can perform a successful measurement of spin, i.e., establish a one-to-one correlation between the system and apparatus states in a suitable basis. According to the philosophy of the environment-induced-decoherence approach, an apparatus coupled to a large number of degrees of freedom (the environment) performs a successful measurement since a trace over all the environment
variables drives the density matrix of the apparatus to a diagonal form, making it classically interpretable. Our belief on the basis of our analysis, however, is that it is not enough for the apparatus to be merely coupled to a large number of degrees of freedom. The apparatus variable must also possess a well-understood classical limit. The failure of our first model was because of the absence of such a limit for a discrete two-level apparatus. Our belief is strengthened by the success of our second model where the apparatus variable - that of the particle trajectory, has a well-defined classical distribution. In our second model we showed how a Stern–Gerlach apparatus coupled to a suitable environment performs a successful measurement of spin in the sense of establishing a one-to-one correspondence between system and apparatus states through a diagonal density matrix. Although our analysis clearly supports the idea of an apparatus variable with a necessarily well-defined classical limit, its establishment requires a more rigorous proof and many more apparatus models need to be analysed to reach a definite conclusion.

In the context of quantum measurement the concept of the emergence of a 'preferred basis' has been discussed in some detail by Zurek. However, all aspects of this 'environment-induced-superselection' are not well-understood and not many systems have been analyzed in detail. The only well-known example is that of the harmonic oscillator for which Zurek has shown that the coherent states emerge as the preferred basis. In Section V of Chapter 2 we showed that for the measurement of spin with a Stern–Gerlach apparatus model with an environment, it is the momentum basis that emerges as the preferred basis in which the correlations with the spin states are established. We also examined in detail the solutions for a free particle and clarified the roles of
position and momentum in the context of preferred bases. Our conclusions differ from that of Zurek's (Prog. Theo. Phys. 89, 281 (1993)). According to our analysis, for a free particle coupled to a bath of harmonic oscillators through the Caldeira-Leggett kind of coordinate-coordinate coupling, it is the momentum basis in which the density matrix becomes diagonal thus making it the preferred basis. The density-matrix is obviously non-diagonal in the position basis as the density matrices in the two bases are related by Fourier transforms. This is contrary to the general expectation and the general belief that the position basis must emerge as the preferred basis since the coupling to the environment is through the position coordinate. Thus our analysis shows that the choice of the preferred basis may not be as straightforward as it seems and many more systems and types of interactions must be considered to get a better insight into it.

The implications of environment-induced-decoherence can be looked for in real experimental situations. In Sections IV and VI of Chapter 2 we analyzed two such situations. The first one is that of a spin-recombination experiment where we briefly indicated what the implications of environmental influence could be on a real experiment. We indicate that if environmental effects cannot be ignored, it is impossible to completely recover spin-coherence. Our second example was that of a system in an E-P-R singlet state. Although many carefully designed experiments have shown the existence of nonlocal quantum correlations - now well-known by their violation of the Bell inequalities, one cannot ignore the effects of the external environment on these correlations. This is particularly relevant when one looks at the practical applications of exploiting quantum correlations, e.g., in 'teleportation' and quantum
computers. Our results show that for the E-P-R singlet state, the environment (modelled by a fluctuating magnetic field) destroys quantum correlations over a characteristic time scale.

In all the studies described above, we adopted the environment-induced decoherence approach. In this approach, state reduction, and hence the emergence of classicality is explained purely within the realm of quantum theory. As mentioned in Chapter 2, this approach is not without criticism and many authors have adopted different approaches to explain state reduction. Ghirardi, Rimini and Weber (Phys. Rev. D 34, 470 (1986)) have proposed a modification of the Schrödinger equation (the continuous spontaneous localization theory) to resolve the measurement problem. This modified linear Schrödinger equation possesses a new term that depends upon a randomly fluctuating force and the dynamics lets microscopic systems spread out and interfere while it prevents macroscopic systems from doing so, thus explaining the emergent 'classicality'. We believe that these theories may not be very different from each other and it is worth looking at the relationships between these various approaches to the problem of state-reduction.

Our second choice for the investigation of the quantum-classical connection was in the quantum fields of light. As is well-known, the most spectacular experiments probing the quantum nature of systems have been done with quantum fields of light. Optical systems provide an extremely rich ground for studying the relationships between the 'quantum' and the 'classical' both theoretically and experimentally. In Chapter 3 we concentrated on quantum fields of light generated in a special class of nonlinear optical processes.
Such fields are known to show various nonclassical and nonlocal features. It is known that the strong correlations between the output modes generated in nonlinear processes, such as multimode parametric amplifiers and four-wave mixing, may lead to a violation of classical inequalities. We proposed a scheme for quantifying these nonclassical features via the parameters of phase-space distribution functions which can be associated with the fields. We considered an optical correlation experiment where two coupled modes are generated in a nonlinear optical process. The fields generated here can be described by a Wigner distribution function which is a Gaussian centered around the mean value of the field. We showed that the Bell inequality for these modes can be expressed as an inequality relating to the parameters of the underlying Wigner distribution function. One can similarly write down inequalities for other known quantum effects and this leads to a more generalized and quantitative description of nonclassicality through the distribution function. Thus, the 'quantum-classical' connection is brought out via the quantum conditions on the distribution function parameters. The treatment in Chapter 3 can be extended to other nonclassical features of light like antibunching and one can work out a unifying description of nonclassicality in light fields in terms of the parameters of the underlying phase-space distribution function.

In the light of the discussions in Chapters 2 and 3, we would like to mention in particular the role of 'environment-induced-decoherence' in the context of optical systems. Measurements in such systems can be explained by the environment-induced decoherence theory in a way similar to that applied to the general problem of quantum measurement in various systems. Optical systems
like two-level atoms are not completely isolated from their environments. They are coupled to a collection of vacuum modes which constitute their environment. It is this coupling which is responsible for the phenomenon of spontaneous emission. It may be noticed that attributes of two-level atoms like level-population etc. are measured by observing the presence (or absence) of spontaneously emitted photons from the respective levels. Thus spontaneous emission processes can be looked as 'apparatus models' in such systems and it is worth exploring the nature of the coupling with the vacuum modes and hence the subsequent dependence of such measurements on the 'decoherence times'.

In Chapter 4 we considered yet another optical system to probe the quantum-classical connection. We examined this connection through the interesting class of two-level systems which are created by lifting the propagation degeneracy of a single longitudinal mode of an optical ring cavity. Such a classical optical system is known to display features that are normally associated with a discrete two-level quantum system. We started from the actual dynamical equations for the electromagnetic field and gave explicit forms for the frequencies of the split modes in terms of the parameters of the reflector. Such systems have been extensively studied in the context of using optical cavities to create two-level systems. Our results differ from the conventional 'coupled-oscillator model' for such systems.

To summarize, in this thesis it has been our attempt to look at some aspects of the quantum-classical connection in a few systems and situations. In the systems that we studied we tried to look at the connection through
approaches which are not outside the realm of quantum theory. This reasserts the fact that for all these systems quantum mechanics is the fundamental theory from which classicality can be explained. A better and complete understanding of the working of quantum mechanics, of course, remains a subject with challenging theoretical and experimental research prospects. This thesis is a modest drop in the ocean!