Description for general public

Objective- The descriptions of the quantum phenomenon and the macroscopic classical world differ significantly not only in their mathematical formulations, but also in their foundational concepts and philosophical consequences. To argue the non-acceptance of quantum mechanics Albert Einstein once said, *'I like to think the moon is there even if I am not looking at it'.* Later, in the groundbreaking works by Bell-Kochen-Specker, the impossibility of measurement independent objective reality of quantum observables is shown. This feature, known as 'quantum contextuality', implies the Einstein's intuition on underlying nature of quantum theory was wrong. The traditional notion of quantum contextuality states that there are quantum measurements whose outcome cannot be predefined in a noncontextual manner i.e., independent of the measurement context among the choices of jointly measurable tests that can be performed together. While a single quantum system exhibits contextuality, Bell theorem shows two subsystems of a larger system possess more surprising nonlocal correlation. Later, a more fundamental notion of contextuality, namely, preparation contextuality, is proposed by Spekkens. If different preparation procedures for a mixed state cannot be distinguished operationally, then, in a preparation noncontextual model, the realist description for those preparations is the same. It has been recently realized that the preparation contextuality is a more fundamental nonclassical feature of quantum mechanics.

Quantum nonlocality and contextuality have revolutionized the field of information processing in last few decades. For instance, nonlocal correlation provides unconditional security in cryptography and randomness generation where the user does not have to trust the device. It also opens up several remarkable possibilities like teleportation, dense coding, advantages in communication complexity tasks etc., which are unachievable in classical communication. Our main objective of this proposal is to - (1) study quantum information processing with preparation contextual resources, (2) propose novel features of nonlocality based on outcome contextuality of local subsystems.

Research- A new information theoretic task, namely, parity oblivious random access code in prepare and measure scenario is proposed as an application of preparation contextuality. In the simplest case, the sender (Alice) is given an input consists of two bits. She is only allowed a single use of a communication channel which transmits systems to send a message to the receiver (Bob) such that no information about the parity of the inputs is encoded. The receiver, apart from the message, also receives an input and depending on that his task is to retrieve one of the bits received his Alice. Firstly, we will propose a general oblivious multiplexing task and with respect to that framework we will characterize the full set of probabilities of all the events in three different theories: preparation noncontextual theories, quantum theory, and post-quantum general probabilistic theories. Next, our goal will be to make full generalization of parity oblivious random access code to higher dimensional system and and in communication network beyond prepare and measure scenario. Based on the oblivious constraint we will propose and study semi-device independent quantum information processing in which no assumptions on the internal working of the preparation and measurement devices will be made. In the second part of the proposal, our first aim is to find fully nonlocal quantum correlation based on state independent contextuality on subsystems which are robust against experimental noise and extend it to multipartite scenario. We will explore the role of local contextuality in the monogamy property of nonlocal correlation.

Significance- The proposed directions of research have significant importance not only in the applications of quantum theory to information processing and communication, but also in understanding quantum foundations more deeply. Characterizing preparation contextuality in an operational approach is essential to quantify it and explore its implications. Such study will provide a new prospect to quantum information processing. Since the oblivious transfer is the building blocks of classical cryptography, this research might yield new perception in cryptography. On the other hand, fully nonlocal correlation and monogamy property of nonlocality are significant in device independent cryptographic scenarios where Alice and Bob can verify a sufficient Bell violation to guarantee that their systems are less correlated with any eavesdropper's system. Thus novel features in this line of studies will have implications in the security proof of device independent information processing. The investigation of generalized monogamy between nonlocality and local contextuality might lead to a universal quantum resource and help to understand the origin of quantum entanglement.