Direct tunneling delay time measurement in an optical lattice

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We report on the measurement of the time required for a wave packet to tunnel through the potential barriers of an optical lattice. The experiment is carried out by loading adiabatically a Bose-Einstein condensate into a 1D optical lattice. A sudden displacement of the lattice by a few tens of nm excites the micromotion of the dipole mode. We then directly observe in momentum space the splitting of the wave packet at the turning points and measure the delay between the reflected and the tunneled packets for various initial displacements. Using this atomic beam splitter twice, we realize a chain of coherent micron-size Mach-Zehnder interferometers at the exit of which we get essentially a wave packet with a negative momentum, a result opposite to the prediction of classical physics.