standing on the ground (which we shall take to be an inertial frame) beside a perfectly flat horizontal turntable, rotating with constant angular velocity \( \omega \). I lean over and throw a frictionless puck so that it slides across the turntable, straight through the center. The puck is subject to zero net force and, as seen from my inertial frame, travels in a straight line. Describe the puck's path as observed by someone sitting at rest on the turntable. This requires careful thought, but you should be able to get a qualitative picture. For a quantitative picture, it helps to use polar coordinates; see Problem 1.46.

### SECTION 1.5 The Third Law and Conservation of Momentum

1.28 ** Go over the steps from Equation (1.25) to (1.29) in the proof of conservation of momentum, but treat the case that \( N = 3 \) and write out all the summations explicitly to be sure you understand the various manipulations.

1.29 ** Do the same tasks as in Problem 1.28 but for the case of four particles (\( N = 4 \)).

1.30 ** Conservation laws, such as conservation of momentum, often give a surprising amount of information about the possible outcome of an experiment. Here is perhaps the simplest example: Two objects of masses \( m_1 \) and \( m_2 \) are subject to no external forces. Object 1 is traveling with velocity \( v \) when it collides with the stationary object 2. The two objects stick together and move off with common velocity \( v' \). Use conservation of momentum to find \( v' \) in terms of \( v \), \( m_1 \), and \( m_2 \).

1.31 ** In Section 1.5 we proved that Newton's third law implies the conservation of momentum. Prove the converse, that if the law of conservation of momentum applies to every possible group of particles, then the interparticle forces must obey the third law. [Hint: However many particles your system contains, you can focus your attention on just two of them. (Call them 1 and 2.) The law of conservation of momentum says that if there are no external forces on this pair of particles, then their total momentum must be constant. Use this to prove that \( F_{12} = -F_{21} \).]

1.32 ** If you have some experience in electromagnetism, you could do the following problem concerning the current situation illustrated in Figure 1.8. The electric and magnetic fields at a point \( r_1 \) due to a charge \( q \) at \( r_2 \) moving with constant velocity \( v \) (with \( v_2 < v \)) are given by

\[
E(r_1) = \frac{1}{4\pi \epsilon_0} \frac{q}{r_1^2} \hat{r}_1 \quad \text{and} \quad B(r_1) = \frac{\mu_0}{4\pi} \frac{v_2 \times r_2}{r_1^2} \times \hat{r}_1
\]

where \( s = r_1 - r_2 \) is the vector pointing from \( r_2 \) to \( r_1 \). (The first of these you should recognize as Coulomb's law.) \( \mathbf{E}_{12} \) and \( \mathbf{B}_{12} \) denote the electric and magnetic forces on charge \( q \) at \( r_1 \) with velocity \( v \), show that \( \mathbf{E}_{12} = (v_2 r_2/c) \mathbf{B}_{12} \). This shows that in the non-relativistic domain it is legitimate to ignore the magnetic force between two moving charges.

1.33 ** If you have some experience in electromagnetism and with vector calculus, prove that the magnetic forces, \( F_{12} \) and \( F_{21} \), between two steady currents obey Newton's third law. [Hint: Let the two currents be \( I_1 \) and \( I_2 \), and let typical points on the two loops be \( r_1 \) and \( r_2 \). If \( d\mathbf{r}_1 \) and \( d\mathbf{r}_2 \) are short segments of the loops, then according to the Biot-Savart law, the force on \( d\mathbf{r}_1 \) due to \( d\mathbf{r}_2 \) is given by

\[
\mathbf{F} = \frac{\mu_0}{4\pi} \frac{I_2}{L} \times (d\mathbf{r}_2 \times \hat{n})
\]

where \( s = r_1 - r_2 \). The force \( F_{12} \) is found by integrating this around both loops. You will need to use the "BAC - CBA" rule to simplify the triple product.\(^\text{11}\)

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