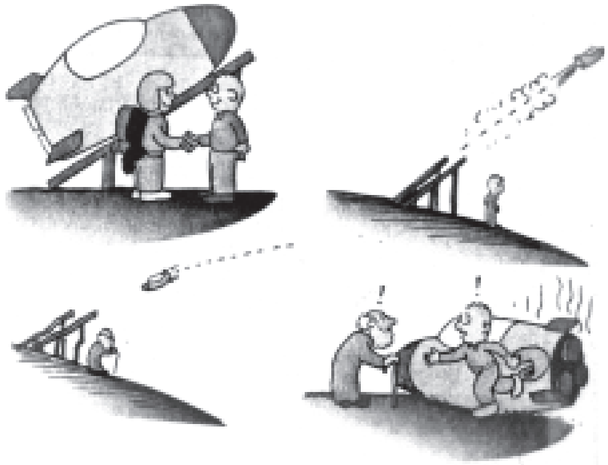
Name ____________________ Class ____________ Date ____________

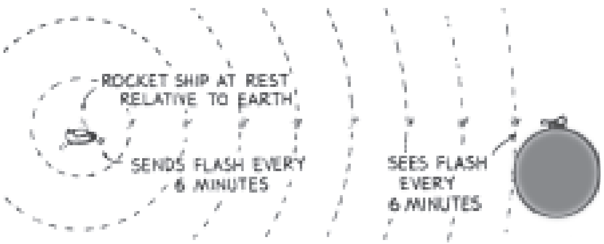
Concept-Development Practice Page **15-1**

The Twin Trip

This is about identical twins, one an astronaut who takes a high-speed round-trip journey while the other twin stays home on Earth. The traveling twin returns younger than the stay-at-home twin. How much younger depends on the relative speeds involved. If the traveling twin maintains a speed of 0.5*c* for 1 year (according to clocks aboard the spaceship), 1.15 years elapse on Earth. For a speed of 0.87*c*, 2 years elapse on Earth. At 0.995*c*, 10 Earth years pass in one spaceship year; the traveling twin ages a single year while the stay-at-home twin ages 10 years.

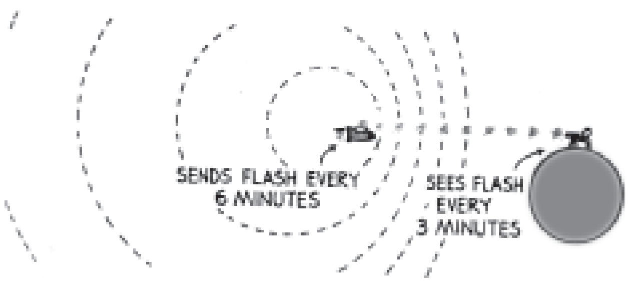


This exercise will show that from the frames of reference of both the Earthbound twin and traveling twin, the Earthbound twin ages more.

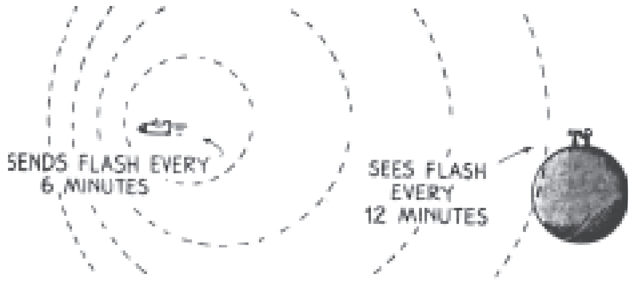


Case 1: No Motion First, consider a spaceship hovering at rest relative to a distant planet (left). Suppose the spaceship sends regularly-spaced brief flashes of light to the planet. The light flashes encounter a receiver on the planet a slight time later at speed *c*. Since there is no relative motion between sender and receiver, successive flashes are received as frequently as they are sent. We'll suppose that a flash is sent from the ship every 6 minutes; after a slight delay, the receiver receives a flash every 6 minutes. Nothing is unusual because no motion is involved.

Case 2: Motion For motion the situation is quite different. Although the speed of the flashes is *c*, regardless of motion, how *frequently* the flashes are seen depends on relative motion. When the ship approaches the receiver, the receiver sees the flashes more frequently. This makes sense because each succeeding flash has less distance to travel as the ship gets closer to the receiver. Flashes are "crowded together" and are seen more frequently. Flashes sent at 6-minute intervals are seen less than 6 minutes apart. We'll suppose the ship is traveling fast enough for the flashes to be seen twice as frequently, at 3-minute intervals (right). This is the Doppler effect (Chapter 25) for light.



Moving away from the receiver stretches the flashes apart and they are seen less frequently. If the ship recedes from the receiver at the same speed and still emits flashes at 6-minute intervals, these flashes are seen by the receiver as stretched to 12-minute intervals. Put another way, they are seen half as frequently, that is, one flash each 12 minutes (right). This makes sense because each succeeding flash has a longer distance to travel as the ship gets farther away from the receiver.



Note the effect of moving away is the opposite of moving closer to the receiver. Although flashes are received twice as frequently when the ship is approaching (6-minute flash intervals are seen every 3 minutes), they're received half as frequently when receding (6-minute flash intervals are seen every 12 minutes).

The light flashes make up a light clock. Any reliable clock would show that 6-minute intervals in the spaceship appear 12 minutes apart when the spaceship recedes and only 3 minutes apart when the ship approaches (that's *twice* as long apart when receding, *half* as long apart when approaching).

1. If the spaceship travels for 1 hour and emits a flash each 6 minutes, how many flashes will be emitted? ____________________

2. The ship sends equally-spaced 6-minute flashes while approaching a receiver. Will these flashes be received equally spaced if the ship approaches at constant velocity while sending flashes?

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3. If the receiver sees these flashes at 3-minute intervals, how much time occurs between receiving the first and the last flash (in the frame of reference of the receiver)?

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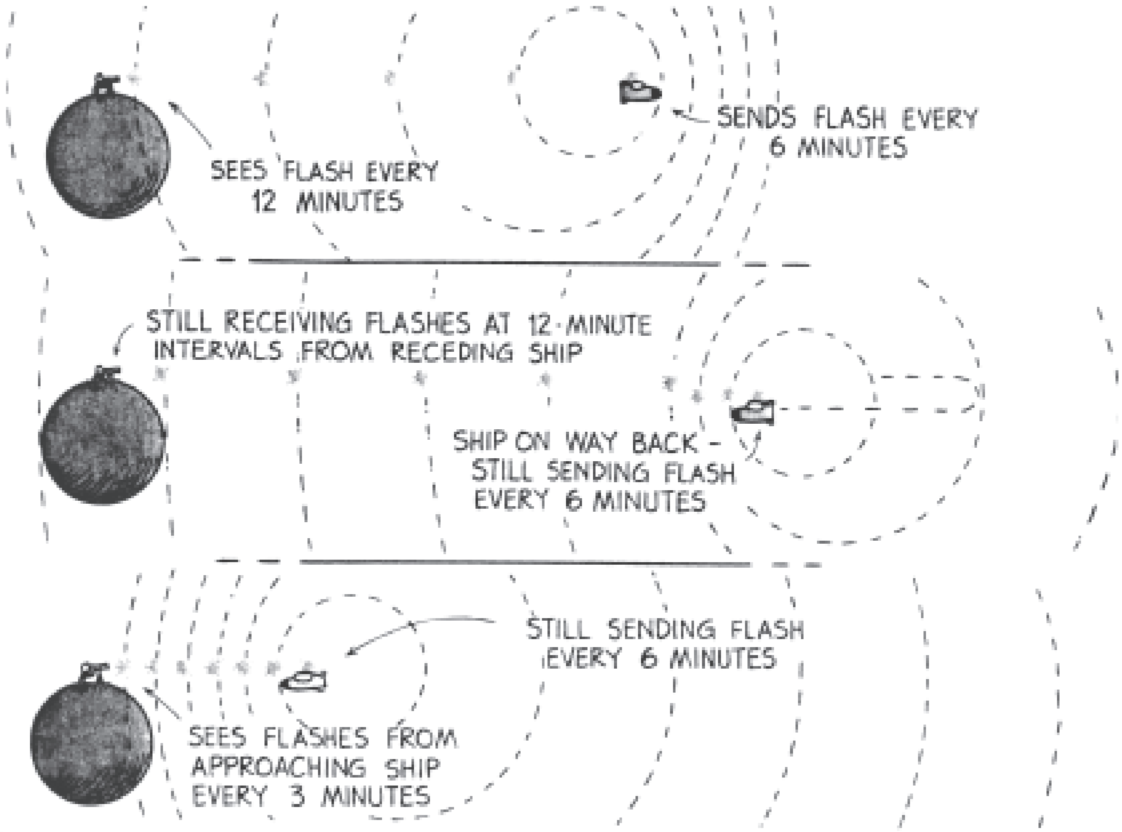
Case 3: The Twins Let's apply this doubling and halving of flash intervals to the twins. Suppose the traveling twin recedes from the Earthbound twin at the same high speed for 1 hour and then quickly turns around and returns in 1 hour. The traveling twin takes a round trip of 2 hours, according to clocks aboard the spaceship. But the time for this round trip will be different as seen in the Earth frame of reference.

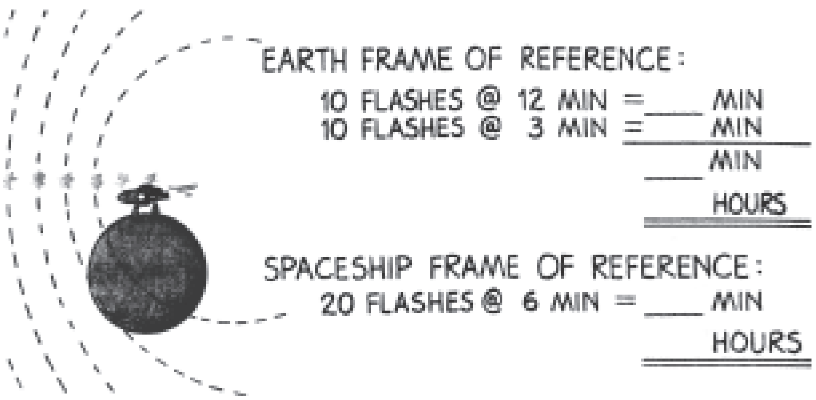
In the figure on the next page we see the ship receding from Earth, emitting a flash each 6 minutes. Due to motion, flashes are received on Earth every 12 minutes. During the hour of going away from Earth, a total of ten flashes are emitted. If the ship departs from Earth at noon, clocks aboard the ship read 1 P.M. when the tenth flash is emitted. What time will it be on Earth when this tenth flash reaches Earth? The answer is 2 P.M. Why? Because the time it takes Earth to receive 10 flashes at 12-minute intervals is 10×12 min = 120 min = 2 hours.

Suppose the spaceship turns around suddenly in a negligibly short time and returns at the same high speed. During the hour of return it emits another ten flashes at 6-minute intervals. These flashes are received every 3 minutes on Earth, so all ten flashes arrive in 30 minutes. A clock on Earth will read 2:30 P.M. when the spaceship completes its 2-hour trip. We see that the Earthbound twin has aged 1/2 hour more than the twin aboard the spaceship!

The Twin Trip—continued

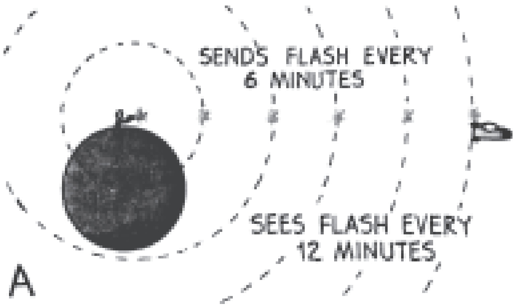


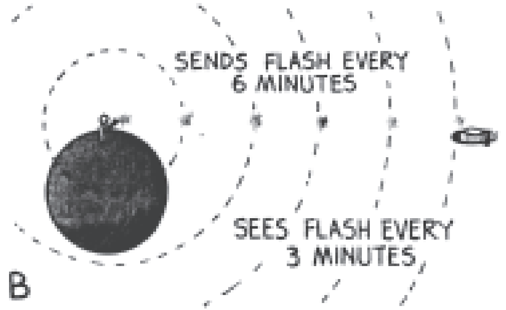
4. Complete the figure below, which summarizes Case 3, by filling in the blanks.



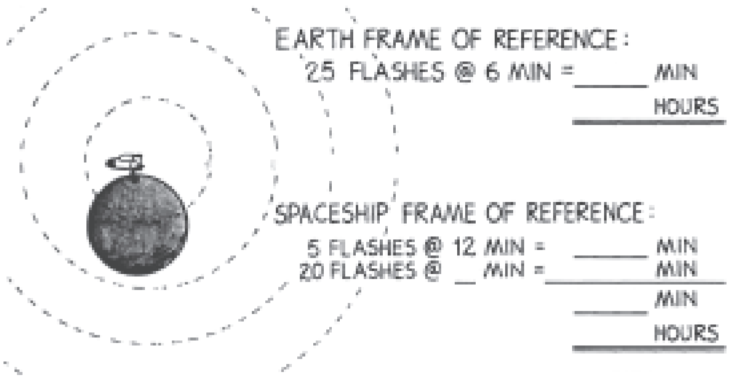
Case 4: Sending and Receiving Twins Interchanged Let's switch sender and receiver and see if the result is the same in both frames of reference. Flashes are emitted from Earth at regularly spaced 6-minute intervals in Earth time, but are seen from the frame of reference of the receding spaceship, at 12-minute intervals (A). This means that a total of *five* flashes are seen by the spaceship during the hour of receding from Earth. During the spaceship's hour of approaching, the light flashes are seen at 3-minute intervals (B), so *twenty* flashes will be seen.

So the spaceship receives a total of 25 flashes during its 2-hour trip. According to clocks on Earth, however, the time it takes to emit the 25 flashes at 6-minute intervals is 25 × 6 min = 150 min = 2.5 hours.





5. Fill in the dashed blanks in the figure, which summarizes Case 4.



Conclusion So both twins agree on the same results, with no dispute as to who ages more. The key factor is that while the stay-at-home twin remains in a single reference frame, the traveling twin experiences two different frames of reference, separated by the acceleration of the spaceship in turning around. So the spaceship experiences two different realms of time, while Earth-bound observers experience a still different but single realm of time. The twins can meet again at the same location in space only at the expense of time.

6. The twin example is often called the twin "paradox" because of the following reasoning: Since motion is relative, the spaceship can be regarded at rest while Earth moves, in which case the twin on the spaceship ages more. Is the situation symmetrical; that is, do both twins occupy the same realm of time? ________ What event separates the ________ realms of time for the traveling twin? ________________________________ In terms of symmetry, is this twin-paradox reasoning correct or incorrect? ______________ Briefly, why?

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CONCEPTUAL PHYSICS