60. (a) In a reference frame fixed on Earth, the ether travels leftward with speed v. Thus, the speed of the light beam in this reference frame is $c - v$ as the beam travels rightward from M to M_1, and $c + v$ as it travels back from M_1 to M. The total time for the round trip is therefore given by

$$t_1 = \frac{d_1}{c - v} + \frac{d_1}{c + v} = \frac{2cd_1}{c^2 - v^2} \; .$$

(b) In a reference frame fixed on the ether, the mirrors travel rightward with speed v, while the speed of the light beam remains c. Thus, in this reference frame, the total distance the beam has to travel is given by

$$d_2{}' = 2\sqrt{d_2^2 + \left[v\left(\frac{t_2}{2}\right)\right]^2}$$

[see Fig. 36-37(h)-(j)]. Thus,

$$t_2 = \frac{d_2{}'}{c} = \frac{2}{c}\sqrt{d_2^2 + \left[v\left(\frac{t_2}{2}\right)\right]^2} \; ,$$

which we solve for t_2:

$$t_2 = \frac{2d_2}{\sqrt{c^2 - v^2}} \; .$$

(c) We use the binomial expansion (Appendix E)

$$(1 + x)^n = 1 + nx + \cdots \approx 1 + nx \qquad (|x| \ll 1) \; .$$

In our case let $x = v/c \ll 1$, then

$$L_1 = \frac{2c^2 d_1}{c^2 - v^2} = 2d_1\left[1 - \left(\frac{v}{c}\right)^2\right]^{-1} \approx 2d_1\left[1 + \left(\frac{v}{c}\right)^2\right] \; ,$$

and

$$L_2 = \frac{2cd_2}{\sqrt{c^2 - v^2}} = 2d_2\left[1 - \left(\frac{v}{c}\right)^2\right]^{-1/2} \approx 2d_2\left[1 + \frac{1}{2}\left(\frac{v}{c}\right)^2\right] \; .$$

Thus, if $d_1 = d_2 = d$ then

$$\Delta L = L_1 - L_2 \approx 2d\left[1 + \left(\frac{v}{c}\right)^2\right] - 2d\left[1 + \frac{1}{2}\left(\frac{v}{c}\right)^2\right] = \frac{dv^2}{c^2} \; .$$

(d) In terms of the wavelength, the phase difference is given by

$$\frac{\Delta L}{\lambda} = \frac{dv^2}{\lambda c^2} \; .$$

(e) We now must reverse the indices 1 and 2, so the new phase difference is

$$\frac{-\Delta L}{\lambda} = -\frac{dv^2}{\lambda c^2} \; .$$

The shift in phase difference between these two cases is

$$\text{shift} = \left(\frac{\Delta L}{\lambda}\right) - \left(-\frac{\Delta L}{\lambda}\right) = \frac{2dv^2}{\lambda c^2} \; .$$

(f) Assume that v is about the same as the orbital speed of the Earth, so that $v \approx 29.8\,\text{km/s}$ (see Appendix C). Thus,

$$\text{shift} = \frac{2dv^2}{\lambda c^2} = \frac{2(10\,\text{m})(29.8 \times 10^3\,\text{m/s})^2}{(500 \times 10^{-9}\,\text{m})(2.998 \times 10^8\,\text{m/s})^2} = 0.40 \; .$$