3. **SSM** ***REASONING*** Since the "police car" is moving relative to the earth observer, the earth observer measures a greater time interval Δt between flashes. Since both the proper time Δt_0 (as observed by the officer) and the dilated time Δt (as observed by the person on earth) are known, the speed of the "police car" relative to the observer can be determined from the time dilation relation, Equation 28.1.

SOLUTION According to Equation 28.1, the dilated time interval between flashes is $\Delta t = \Delta t_0 / \sqrt{1-(v^2/c^2)}$, where Δt_0 is the proper time. Solving for the speed v, we find

$$v = c\sqrt{1-\left(\frac{\Delta t_0}{\Delta t}\right)^2} = (3.0\times10^8\ \text{m/s})\sqrt{1-\left(\frac{1.5\ \text{s}}{2.5\ \text{s}}\right)^2} = \boxed{2.4\times10^8\ \text{m/s}}$$

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4. ***REASONING*** The total time for the trip is one year. This time is the proper time interval Δt_0, because it is measured by an observer (the astronaut) who is at rest relative to the beginning and ending events (the times when the trip started and ended) and who sees them at the same location in spacecraft. On the other hand, the astronaut measures the clocks on earth to run at the dilated time interval Δt, which is the time interval of one hundred years**.** The relation between the two time intervals is given by Equation 28.1, which can be used to find the speed of the spacecraft.

SOLUTION The dilated time interval Δt is related to the proper time interval Δt_0 by $\Delta t = \Delta t_0 / \sqrt{1-\left(v^2/c^2\right)}$. Solving this equation for the speed v of the spacecraft yields

$$v = c\sqrt{1-\left(\frac{\Delta t_0}{\Delta t}\right)^2} = c\sqrt{1-\left(\frac{1\ \text{yr}}{100\ \text{yr}}\right)^2} = \boxed{0.999\,95c} \qquad (28.1)$$

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10. ***REASONING*** The distance between earth and the center of the galaxy is the proper length L_0, because it is the distance measured by an observer who is at rest relative to the earth and the center of the galaxy. A person on board the spaceship is moving with respect to them and measures a contracted length L that is related to the proper length by Equation 28.2 as $L = L_0\sqrt{1-\left(v^2/c^2\right)}$. The contracted distance is also equal to the product of the spaceship's speed v the time interval measured by a person on board the spaceship. This time interval is the proper time interval Δt_0 because the person on board the spaceship measures the beginning and ending events (the times when the trip starts and ends) at the same location relative to a coordinate system fixed to the spaceship. Thus, the contracted distance is also
$L = v\Delta t_0$. By setting the two expressions for L equal to each other, we can find the how long the trip will take according to a clock on board the spaceship.

SOLUTION Setting $L = L_0\sqrt{1-\left(v^2/c^2\right)}$ equal to $L = v\Delta t_0$ and solving for the proper time interval Δt_0 gives

$$\Delta t_0 = \frac{L_0}{v}\sqrt{1-\left(v^2/c^2\right)}$$

$$= \frac{(23\,000\text{ ly})\left(\dfrac{9.47\times10^{15}\text{ m}}{1\text{ ly}}\right)}{0.9990\left(3.00\times10^{8}\text{ m/s}\right)}\sqrt{1-\left[\frac{(0.9990c)^2}{c^2}\right]}\left(\frac{1\text{ yr}}{3.16\times10^{7}\text{ s}}\right) = \boxed{1.0\times10^{3}\text{ yr}}$$

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11. **SSM** ***REASONING AND SOLUTION*** The length L_0 that the person measures for the UFO when it lands is the proper length, since the UFO is at rest with respect to the person. Therefore, from Equation 28.2 we have

$$L_0 = \frac{L}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{230 \text{ m}}{\sqrt{1-\frac{(0.90\,c)^2}{c^2}}} = \boxed{530 \text{ m}}$$

22. ***REASONING AND SOLUTION*** The mass equivalent is given by E_0 = KE = mc^2 or

$$m = \frac{\text{KE}}{c^2} = \frac{7.8\times10^{-13}\ \text{J}}{\left(3.00\times10^{8}\ \text{m/s}\right)^2} = \boxed{8.7\times10^{-30}\ \text{kg}} \qquad (28.5)$$

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25. ***REASONING AND SOLUTION***

a. The energy Q needed to heat the water is

$$Q = cm\,\Delta T = [4186\ \text{J/(kg·C°)}](4.0\ \text{kg})(60.0\ \text{°C} - 20.0\ \text{°C}) = \boxed{6.7\times10^{5}\,\text{J}} \qquad (12.4)$$

b. Using $\Delta E_0 = (\Delta m)c^2$, we have

$$\Delta m = \Delta E_0/c^2 = (6.7\times10^{5}\ \text{J})/(3.00\times10^{8}\ \text{m/s})^2 = \boxed{7.4\times10^{-12}\ \text{kg}} \qquad (28.5)$$

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1. SSM ***REASONING*** According to Equation 29.3, the work function W_0 is related to the photon energy hf and the maximum kinetic energy KE_{max} by $W_0 = hf - \text{KE}_{\text{max}}$. This expression can be used to find the work function of the metal.

SOLUTION KE_{max} is 6.1 eV. The photon energy (in eV) is, according to Equation 29.2,

$$hf = \left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00\times10^{15}\ \text{Hz}\right)\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right) = 12.4\ \text{eV}$$

The work function is, therefore,

$$W_0 = hf - \text{KE}_{\text{max}} = 12.4\ \text{eV} - 6.1\ \text{ev} = \boxed{6.3\ \text{eV}}$$

3. ***REASONING AND SOLUTION*** The energy of a single photon is

$$E = hf = (6.63 \times 10^{-34}\ \text{J·s})(98.1 \times 10^{6}\ \text{Hz}) = 6.50 \times 10^{-26}\ \text{J}$$

The number of photons emitted per second is

$$\frac{\text{Power radiated}}{\text{Energy per photon}} = \frac{5.0 \times 10^{4}\ \text{W}}{6.50 \times 10^{-26}\ \text{J}} = \boxed{7.7 \times 10^{29}\ \text{photons/s}}$$

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4. ***REASONING*** The photons of this wave must carry at least enough energy to equal the work function. Then the electrons are ejected with zero kinetic energy. Since the energy of a photon is $E = hf$ according to Equation 29.2, where f is the frequency of the wave, we have that $W_0 = hf$. Equation 16.1 relates the frequency to the wavelength λ according to $f = c/\lambda$, where c is the speed of light. Thus, it follows that $W_0 = hc/\lambda$.

SOLUTION Using Equations 29.2 and 16.1, we find that

$$W_0 = \frac{hc}{\lambda} = \frac{\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00\times10^{8}\ \text{m/s}\right)}{485\times10^{-9}\ \text{m}} = 4.10\times10^{-19}\ \text{J}$$

Since 1 eV = 1.60×10^{-19} J, it follows that

$$W_0 = \left(4.10\times10^{-19}\ \text{J}\right)\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right) = \boxed{2.56\ \text{eV}}$$

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5. **SSM** ***REASONING*** The energy of the photon is related to its frequency by Equation 29.2, $E = hf$. Equation 16.1, $v = f\lambda$, relates the frequency and the wavelength for any wave.

SOLUTION Combining Equations 29.2 and 16.1, and noting that the speed of a photon is *c*, the speed of light in a vacuum, we have

$$\lambda = \frac{c}{f} = \frac{c}{(E/h)} = \frac{hc}{E} = \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(3.0\times10^{8}\ \text{m/s})}{6.4\times10^{-19}\ \text{J}} = 3.1\times10^{-7}\ \text{m} = \boxed{310\ \text{nm}}$$