1. \( E = h\nu = (6.63 \times 10^{-34} \text{ J s}) (6.8 \times 10^{15} \text{ Hz}) = 4.5 \times 10^{-18} \text{ J} \)

2. \( E = h\nu = (6.63 \times 10^{-34} \text{ J s}) (7.91 \times 10^{10} \text{ Hz}) = 5.26 \times 10^{-23} \text{ J} \)

3. \( \frac{3.00 \times 10^8 \text{ m/s}}{5.89 \times 10^{-3} \text{ m}} = (5.09 \times 10^4 \text{ Hz}) (6.63 \times 10^{-34} \text{ J s}) = 3.37 \times 10^{-19} \text{ J} \)

4. \( \frac{3.00 \times 10^9 \text{ m}}{746.4 \times 10^{-9} \text{ m}} = (4.02 \times 10^4 \text{ Hz}) (6.63 \times 10^{-34} \text{ J s}) = 2.66 \times 10^{-23} \text{ J} \)

5. \( E = h\nu = (6.63 \times 10^{-34} \text{ J s}) (2.4 \times 10^9 \text{ Hz}) = 1.59 \times 10^{-25} \text{ J} \)

6. \( \frac{3.00 \times 10^8 \text{ m/s}}{500 \times 10^3 \text{ m}} = (6.00 \times 10^4 \text{ Hz}) (6.63 \times 10^{-34} \text{ J s}) = 3.98 \times 10^{-19} \text{ J} \)

7. \( \frac{E}{h} = \frac{2.39 \times 10^{-18} \text{ J}}{6.63 \times 10^{-34} \text{ J s}} = 3.60 \times 10^{15} \text{ Hz} \)

8. \( \frac{E}{h} = \frac{1.4 \times 10^{-21} \text{ J}}{6.63 \times 10^{-34} \text{ J s}} = 2.11 \times 10^{12} \text{ Hz} \)

9. \( 1.4 \times 10^{-14} \text{ J} \) or 0.0001425

10. \( f = \frac{E}{h} = \frac{3.00 \times 10^8 \text{ m/s}}{2.11 \times 10^{12} \text{ Hz}} = 1.42 \times 10^{14} \text{ m/s} \)

11. \( \frac{4.34}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{6.91 \times 10^{14} \text{ Hz}} (6.63 \times 10^{-34} \text{ J s}) = 4.58 \times 10^{-19} \text{ J} \)
Max Planck explained that energy was transferred in chunks known as **quanta**, equal to $\hbar v$. The variable $h$ is Planck's constant equal to $6.6262 \times 10^{-34}$ J·s and the variable $v$ represents the frequency in 1/s, s$^{-1}$, or Hz (Hertz). This equation allows the calculation of the energy of photons, given their frequency. If the wavelength is given, the energy can be determined by first using the light equation ($c = v\lambda$) to find the frequency, then using Planck's equation to calculate energy.

<table>
<thead>
<tr>
<th>Known</th>
<th>Problem-Solving Strategy</th>
<th>Unknown</th>
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<tbody>
<tr>
<td>Frequency ($v$)</td>
<td>$E = hv$</td>
<td>Energy ($E$)</td>
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<tr>
<td>Wavelength ($\lambda$)</td>
<td>$v = \frac{c}{\lambda}$</td>
<td>Frequency ($v$)</td>
</tr>
<tr>
<td>Energy ($E$)</td>
<td>$v = \frac{E}{h}$</td>
<td>Wavelength ($\lambda$)</td>
</tr>
</tbody>
</table>

**Useful Equations**
- $c = v\lambda$
- $c = 3.00 \times 10^8$ m/s
- $E = hv$
- $h = 6.63 \times 10^{-34}$ J·s
- $1$ nm = $1 \times 10^{-9}$ m
- $1$ kJ = $1000$ J

**Example:** Light with a wavelength of 525 nm is green. Calculate the energy in joules for a green light photon.

- **First** find the frequency: $v = \frac{c}{\lambda}$
  
  \[
  \frac{c}{525 \text{ nm}} = \frac{3.00 \times 10^8 \text{ m/s}}{525 \text{ nm} \times 1 \times 10^{-9} \text{ m}} = \frac{3.00 \times 10^{14} \text{ s}^{-1}}{5.71 \times 10^{14} \text{ s}^{-1}} = 5.71 \times 10^{14} \text{ Hz}
  \]

- **Second** find the energy

  \[
  E = (6.6262 \times 10^{-34} \text{ J} \cdot \text{s})(5.71 \times 10^{14} \text{ s}^{-1}) = 3.78 \times 10^{-19} \text{ J/particle}
  \]

**Use the equations above to answer the following questions.**

1. Ultraviolet radiation has a frequency of $6.8 \times 10^{15}$ Hz. Calculate the energy, in joules, of the photon.
2. Find the energy, in joules per photon, of microwave radiation with a frequency of $7.91 \times 10^{10}$ Hz.
3. A sodium vapor lamp emits light photons with a wavelength of $5.89 \times 10^{-7}$ m. What is the energy of these photons?
4. One of the electron transitions in a hydrogen atom produces infrared light with a wavelength of 746.4 nm. What amount of energy causes this transition?
5. Find the energy in kJ for an x-ray photon with a frequency of $2.4 \times 10^{18}$ s$^{-1}$.
6. A ruby laser produces red light that has a wavelength of 500 nm. Calculate its energy in joules.
7. What is the frequency of UV light that has an energy of $2.39 \times 10^{18}$ J?
8. What is the wavelength and frequency of photons with an energy of $1.4 \times 10^{21}$ J?
9. What is the energy of a light that has 434 nm?
10. What is the wavelength of a light that has a frequency of $3.42 \times 10^{11}$ Hz?

\[ \lambda = \frac{c}{f} = \frac{3.00 \times 10^8}{3.42 \times 10^{11}} = 9.6 \times 10^{-7} \text{ m} \]