Problem 1)

```
In[1]:= M = UnitConvert[sodium ELEMENT [atomic mass], "Kilograms"]; StringForm["M = ``", M]
        λ = Quantity[589, "nanometers"];
        k = 2π/λ; StringForm["k = ``", UnitConvert[k, "inverse nm"] // N]
        p = ℏ k; StringForm["p = ``", UnitConvert[p, "Kg m/s"] // N]
        v = p/M; StringForm["v = ``", UnitConvert[v, "cm/s"]]
```

Out[1]= $M = 3.81754100 \times 10^{-26}$ kg

Out[3]= $k = 0.0106675$ /nm

Out[4]= $p = 1.12497 \times 10^{-27}$ kg m/s

Out[5]= $v = 2.94684318$ cm/s

```
In[6]:= λ' = (2π c)/((2π c)/λ - k v); StringForm["Doppler shifted frequency λ' = ``. So, Δλ = ``", λ', λ' - λ]
```

Out[6]= Doppler shifted frequency $\lambda' = 589.0000000578964075$ nm . So, $\Delta\lambda = 5.78964075 \times 10^{-8}$ nm

Problem 2)

```
In[7]:= γ2 = 2π Quantity[10, "MHz"];
        T = (ℏ γ2)/(4 k); StringForm["T_D = ``", UnitConvert[T, "μK"] // N]
        StringForm["T_R = ``", UnitConvert[p^2/(M k), "μK"]]
```

Out[8]= $T_D = 119.981$ μK

Out[9]= $T_R = 2.40112338$ μK

Problem 3)

In[10]:=
```
Ω0 = 2 π Quantity[20, "MHz"];
v = Quantity[200, "m/s"];
λ = Quantity[628, "nm"];
δ' = Quantity[1, "GHz"];
M = Quantity[23, "amu"];
```
$$\gamma' = \frac{\gamma_2}{2}\sqrt{1 + 2\frac{\Omega_0{}^2}{\gamma_2{}^2}};$$
$$\beta = \hbar\, k^2\, \Omega_0{}^2 \frac{\gamma_2\, \delta}{2\left(\delta^2 + (\gamma')^2\right)^2};$$
```
F = v β;
```

In[18]:=
```
{maxForce, detuning} = Maximize[{F, {-δ' < δ < δ'}}, δ];
```

In[19]:=
```
StringForm["A maximum force of `` is achieved by δ = ``",
 UnitConvert[maxForce, "aN"] // N,
 UnitConvert[δ /. detuning, "MHz"] // N]
StringForm["This force produces an acceleration of ``",
 maxForce / M // UnitConvert]
```

Out[19]=

A maximum force of 0.461906 aN is achieved by δ = 54.414 MHz

Out[20]=

This force produces an acceleration of 1.209418168×10^7 m/s^2

Problem 4)

In[21]:=
```
P = Quantity[5, "mW"];
a = Quantity[4, "mm^2"];
γ2 = 2 π Quantity[6, "MHz"];
λ = Quantity[780, "nm"];
μ = -0.57 e a0 ;
M = UnitConvert[{ rubidium-85 ISOTOPE [ atomic mass ]}, "Kg"];
```
$$k = \frac{2\pi}{\lambda};\ I = \frac{P}{a};\ \delta = \frac{3}{2}\gamma_2;$$
$$\Omega_0 = \sqrt{\frac{2\,\mathrm{Abs}[\mu]^2\, I}{\hbar^2\, \varepsilon_0\, c}};$$
$$E_r = \mathrm{UnitConvert}\left[\frac{\hbar^2 k^2}{2M}, \text{"J"}\right][[1]];$$

In[46]:=
```
V = UnitConvert[ħ Ω0^2/(4 δ), "J"];
StringForm["In units of the recoil energy, the well has a depth of ``", V/Er // N]
Ed = ħ γ2/4;
StringForm[
 "Doppler cooling can achieve atomic CoM energies (in units of the well depth) of ``",
 Ed/V]
```

$$V = \text{UnitConvert}\left[\frac{\hbar\,\Omega_0^2}{4\,\delta}, \text{"J"}\right];$$

$$\text{StringForm}\left[\text{"In units of the recoil energy, the well has a depth of ``"}, \frac{V}{E_r} \;//\; N\right]$$

$$E_d = \frac{\hbar\,\gamma_2}{4};$$

$$\text{StringForm}\left[\text{"Doppler cooling can achieve atomic CoM energies (in units of the well depth) of ``"}, \frac{E_d}{V}\right]$$

Out[47]=

In units of the recoil energy, the well has a depth of 4.587955144457358`*^7

Out[49]=

Doppler cooling can achieve atomic CoM energies (in units of the well depth) of 8.465495043156354`*^-6

In[32]:=

$$P = \text{Quantity}[100, \text{"mW"}];$$

$$a = \pi\,\text{Quantity}[10, \text{"}\mu\text{m"}]^2;$$

$$I = \frac{P}{a};\ \delta = 3\,\gamma_2;$$

$$\Omega_0 = \sqrt{\frac{2\,\text{Abs}[\mu]^2\,I}{\hbar^2\,\varepsilon_0\,c}};$$

In[38]:=

$$V = \text{UnitConvert}\left[\frac{\hbar\,\Omega_0^2}{4\,\delta}, \text{"J"}\right];$$

$$\text{StringForm}\left[\text{"In units of the recoil energy, the well has a depth of ``"}, \frac{V}{E_r}\right]$$

Out[39]=

In units of the recoil energy, the well has a depth of 4.587955144457358`*^7

In[44]:=

$$E_d = \frac{\hbar\,\gamma_2}{4};$$

$$\text{StringForm}\left[\text{"Doppler cooling can achieve atomic CoM energies (in units of the well depth) of ``"}, \frac{E_d}{V}\right]$$

Out[45]=

Doppler cooling can achieve atomic CoM energies (in units of the well depth) of 8.465495043156354`*^-6