# 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 λ' = 589.0000000578964075 nm . So, Δλ = $5.78964075 \times 10^{-8}$ 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 $1.209418168 \times 10^{7}$ 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"];
```

$$k = \frac{2\pi}{\lambda};\ I = \frac{P}{a};\ \delta = \frac{3}{2}\gamma_2;$$

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

$$E_r = \mathrm{UnitConvert}\left[\frac{\hbar^2 k^2}{2 M}, \text{"J"}\right][[1]];$$

In[30]:=
```
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

ω̃ = Sqrt[V k^2/M] [[1]];

StringForm["The frequency spacing near the bottom of the well is ``", UnitConvert[ω̃/(2 π), "MHz
```

Out[31]= In units of the recoil energy, the well has a depth of 360.33715442066836`

Out[33]= Doppler cooling can achieve atomic CoM energies (in units of the well depth) of 1.077860305

Out[35]= The frequency spacing near the bottom of the well is 0.103679 MHz

In[36]:=
```
P = Quantity[100, "mW"];
a = π Quantity[10, "μm"]^2;
I = P/a; δ = 3 γ2;

Ω0 = Sqrt[2 Abs[μ]^2 I/(ℏ^2 ε0 c)];
```

In[40]:=
```
V = UnitConvert[ℏ Ω0^2/(4 δ), "J"];

StringForm["In units of the recoil energy, the well has a depth of ``", V/Er]
```

Out[41]= In units of the recoil energy, the well has a depth of 4.587955144457358`*^7

In[42]:=
```
Ed = ℏ γ2/4;

StringForm["Doppler cooling can achieve atomic CoM energies (in units of the well depth) of
```

Out[43]= Doppler cooling can achieve atomic CoM energies (in units of the well depth) of 8.465495043

In[44]:=
```
ω̃ = Sqrt[V k^2/M][[1]];
StringForm["The frequency spacing near the bottom of the well is ``", UnitConvert[ω̃/(2 π), "MH
```

$$\tilde{\omega} = \sqrt{\frac{V\,k^2}{M}}[\![1]\!];$$

Out[45]= The frequency spacing near the bottom of the well is 36.9951 MHz