1a)

p-type: every boron atom adds a hole $\rightarrow p = 10^{16} \frac{1}{cm^3}$

How many electrons? → law of mass action

$np = (n_i)^2 \qquad n = \frac{n_i^2}{p}$

$n = \frac{(1{,}5 \cdot 10^{10} \frac{1}{cm^3})^2}{10^{16} \frac{1}{cm^3}} = 2{,}25 \cdot 10^4 \frac{1}{cm^3}$

n-type: every phosphorous adds a electron $\rightarrow n = 10^{18} \frac{1}{cm^3}$

How many holes? → law of mass action

$np = n_i^2 \qquad p = \frac{n_i^2}{n}$

$p = \frac{(1{,}5 \cdot 10^{10} \frac{1}{cm^3})^2}{10^{18} \frac{1}{cm^3}} = ~~1{,}5 \cdot 10~~ \; 225 \, cm^{-3}$

b) The voltage is dependent on the doping concentration via:

$N_A N_D = (n_i)^2 e^{\left(\frac{q V_{bi}}{k_B T}\right)}$

This becomes: $V_{bi} = \frac{k_B T}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right) = \frac{1{,}38 \cdot 10^{-23} \cdot 300}{1{,}602 \cdot 10^{-19}} \ln\left(\frac{10^{16} \, 10^{18}}{(1{,}5 \cdot 10^{10})^2}\right) = 0{,}81 V$

c) Width of depletion region $W = \sqrt{\frac{2 \varepsilon_r \varepsilon_0}{q} V_{bi} \left(\frac{1}{N_A} + \frac{1}{N_D}\right)} = \sqrt{\frac{2 \cdot 11{,}7 \cdot 8{,}854 \cdot 10^{-14}}{1{,}602 \cdot 10^{-19}} \cdot 0{,}81 V \left(\frac{1}{10^{16}} + \frac{1}{10^{18}}\right)}$

$= 0{,}325 \mu m$

2) current of a pn-junction under light:

$J(V) = J_0 \left(e^{\left(\frac{qV}{k_B T}\right)} - 1\right) - J_{Ph}$

Since $J(V_{oc}) = 0$ it follows:

$V_{oc} = \frac{k_B T}{q} \ln\left(\frac{J_{Ph}}{J_0} + 1\right) = \frac{1{,}38 \cdot 10^{-23} \cdot 300}{1{,}602 \cdot 10^{-19}} \ln\left(\frac{35}{1{,}35 \cdot 10^{-10}} + 1\right) = 0{,}67 V$

3)

b is ~~not~~ correct

because:

The open circuit voltage can be expressed as: $V_{OC} = \frac{2 k_B T}{q} \ln\left(\frac{g_L \tau_0}{n_i}\right)$

The doping increases the voltage by changing the fermi levels.

4) – Very important for exam to know all I_{SC}, V_{OC}, FF

a) From the graph it looks like $I = 41 A$

The solar cell area is $40 cm \cdot 40 cm = 1600 cm^2 = A$

The current density is therefore: $J_{SC} = \frac{41 A}{1600 cm^2} = 0{,}0256 \frac{A}{cm^2} = 25{,}6 mA \cdot \frac{1}{cm^2}$

4)

b) From the graph it looks like V(OC)=0,6V
The fill factor is therefore:

$$FF = \frac{P_{max}}{I_{sc} V_{oc}} = \frac{19{,}5\,W}{41A \cdot 0{,}6V} = 0{,}793$$

c) The efficiancy is determined by comparing energy out to energy in:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{FF \cdot V_{oc} \cdot I_{sc}}{P_{in}} = \frac{0{,}793 \cdot 0{,}6V \cdot 25\,mA\,\frac{1}{cm^2}}{100\,mW\,\frac{1}{cm^2}} = 12{,}2\%$$

d) The voltage drop can be determined by the formula:

$$\Delta U = \Delta R \cdot I = 41A \cdot 0{,}002\,\Omega = 0{,}082\,V$$

The change in FF is proportional to the change in U

$$\Delta FF = \frac{\Delta U}{U} FF = \frac{0{,}082\,V}{0{,}6V} \cdot 0{,}793 = 0{,}108$$

The new FF is therefore $FF = 0{,}793 - 0{,}108 = 0{,}685$