assignment5

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Course 46030 Electrical energy systems Fall 23
Assignment 5 - 30th October 2023
Group 9:
Anders Henriksen s206120
Casper Helvig Larsen s223873
Katrine Lodahl Rønn s223888
Morten Hay Sørensen s223872

```
[2]: #imports
     from sympy import *
     from sympy.physics.units import *
     import matplotlib.pyplot as plt
     init_printing()
```

Problem 1.1)
The given values are inserted into the equation for U_T

```
[18]: IS = 1e-10 #A
      k = 1.38e-23 #J/K
      T = 300 #K
      q = 1.602e-19 #C
      IF, UF = symbols('I_F U_F')
      UT = k*T/q
      print(f"UT = {round(UT,4)}V")
```

UT = 0.0258V

The equation for I_F as a function of U_F is given as eqn1 while U_F as function of I_F is given as eqn2. eqn2 is plottet over the interval $I_F \in [0, 10]$

```
[8]: eqn1 = Eq(IF, IS*(exp(UF/UT)-1))
     eqn2 = Eq(UF, UT*log(IF/IS+1))

     plot(eqn2.rhs, (IF, 0, 10), xlabel='IF (A)', ylabel='UF (V)', title='Diode␣
      ↪Characteristic Curve')
```

Diode Characteristic Curve
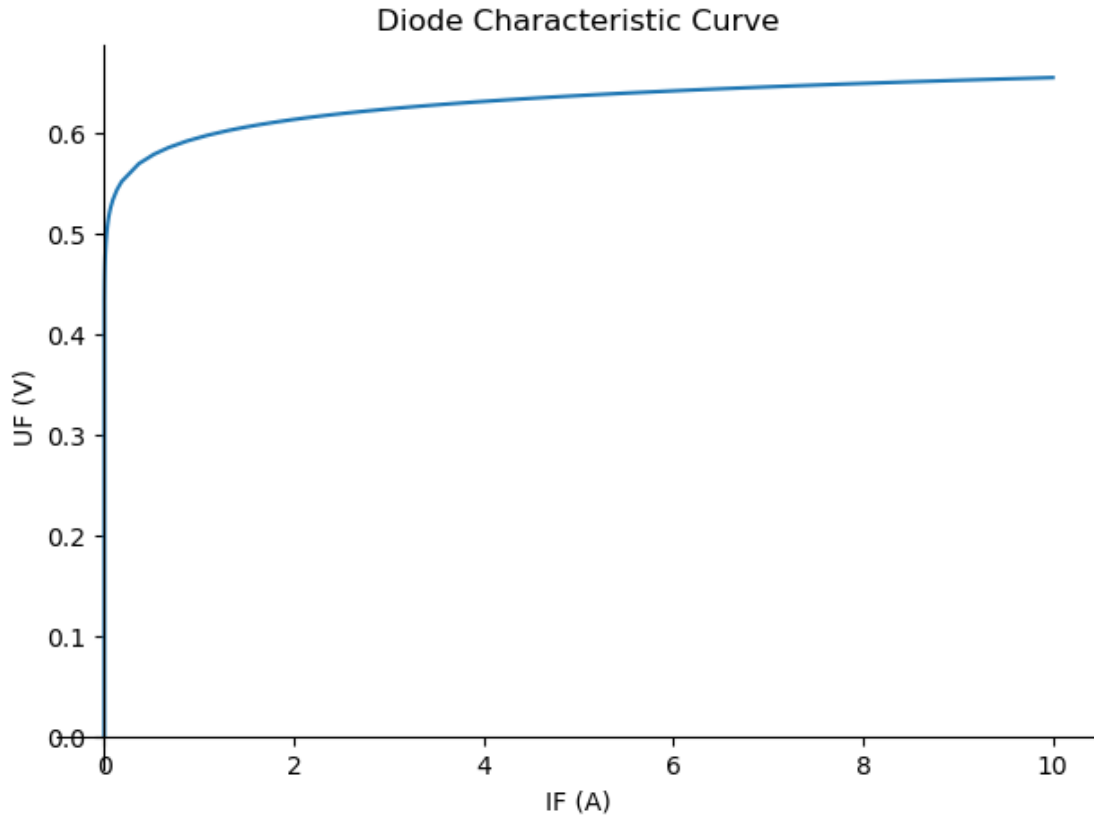
[8]: `<sympy.plotting.plot.Plot at 0x7f0e7d2e7a00>`

Here it can be seen, that the diode allows current to pass from around $0.5V$ to $0.6V$

Problem 1.2)
The new temperature is used to calculate a new U_{T2}. This is used to calculate the forward voltage when the forward current is $5A$ in the cases with $300K$ and $200K$ respectively

```
[17]: T2 = 200  #K
UT2 = k*T2/q
IF2 = 5  #A
UF2 = Eq(Symbol('U_{F200K}'), UT2*log(IF2/IS+1))
eqn2.subs({UF:Symbol('U_F300K'),IF:5}).evalf(3), UF2.evalf(3)
```

[17]: $(U_{F300K} = 0.637, \ U_{F200K} = 0.424)$

Both results are in Volts. From this it can be seen that the drop in temperature gives a reduction in forward voltage of about $0.2V$

Problem 1.3)
An explenation of the semiconductor concept is that a material that normally cannot conduct current can become a conductor if the valens electrons in the atoms in the crystal become excited and leave the atoms. This creates charge imbalances within the crystal that leads to a current. By

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doping a crystal of tetravalent silicon atoms with trivalent boron and pentavalent phosphorus, these charge balances can be induced to create a pn-junction to block current until sufficient voltage is applied over the diode.

Problem 2.a) Yes. The voltage drop must be the same across both diodes. Since the forward voltage depends on the forward current, these forward currents must differ if the diodes have different characteristics.

Problem 2.b)
By using the equation for U_F as a fundtion of the diode (forward) current I_D as well as KCL, a system of three equations can be made. It is assumed that U_F and U_T is the same for both diodes while I_S is different between the diodes.

[66]:
```
#Symbols are defined
UD1,UD2,UT,ID1,ID2,IS1,IS2,Iin = symbols('U_{D1} U_{D2} U_T I_{D1}␣
 ↪I_{D2},I_{S1} I_{S2} I_{in}')

#The two eqtions for the forward voltage are defined
eqn1 = Eq(UF, UT*log(ID1/IS1+1))
eqn2 = Eq(UF, UT*log(ID2/IS2+1))

#The KCL equation for the current is defined
eqn3 = Eq(Iin, ID1+ID2)

#These equtions are printed here
eqn1,eqn2,eqn3
```

[66]:
$$\left(U_F = U_T \log \left(\frac{I_{D1}}{I_{S1}} + 1 \right), \ U_F = U_T \log \left(\frac{I_{D2}}{I_{S2}} + 1 \right), \ I_{in} = I_{D1} + I_{D2} \right)$$

This system of equations can be solved to get the forward currents as a function of the saturation currents and the total current; I_{S1}, I_{S2}, I_{in}

[88]:
```
sol = solve([eqn1,eqn2,eqn3],(ID1,ID2,UF))[0]
Eq(ID1,sol[0]),Eq(ID2,sol[1])
```

[88]:
$$\left(I_{D1} = \frac{I_{S1} I_{in}}{I_{S1} + I_{S2}}, \ I_{D2} = \frac{I_{S2} I_{in}}{I_{S1} + I_{S2}} \right)$$

Here it can be seen, that the diode currents depends on the proportion of a diode's saturation to the sum of parallel saturation currents multiplied by the total current

Problem 3.a)
To estimate the dynamical potential and voltages, it is necessary to fit a tangent line to the function. By assuming the majority of the graph is linear, two suitable points have been read from the graph $(1.2V, 25A), (1.4, 42.5A)$. The dynamic resistance between these points is given as the coefficient of the difference in voltage and the difference in current

[21]:
```
#Points are defined
U1,I1 = 1.2*volt,25*ampere
U2,I2 = 1.4*volt,42.5*ampere
```

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```
#The dynamic resistance is calculated as the slope of the line between the two␣
  ↪points
RD = convert_to(((U2-U1)/(I2-I1)).simplify(),ohm)
Eq(Symbol('R_D'),RD).evalf(3)
```

[21]: $R_D = 0.0114\Omega$

The dynamic voltage is the intercept of the line through the points and the current-axis

[22]:
```
UD = convert_to(U1-RD*I1,volt)
Eq(Symbol('U_D'),UD).evalf(3)
```

[22]: $U_D = 0.914\text{V}$

Problem 3.2)
The junction loss can be estimated from the values calulated above and the given average and RMS currents as $P_D = U_D \cdot I_{AV} + R_D \cdot I_{RMS}^2$

[24]:
```
#The given currents are defined
IRMS = 25*ampere
IAV = 12*ampere

#The junction loss is calculated with the given formula
P=UD*IAV + convert_to(RD*IRMS**2,watt)
Eq(Symbol('P_D'),convert_to(P.simplify(),watt)).evalf(3)
```

[24]: $P_D = 18.1\text{W}$

Problem 4.a)
In the case with antiparallel diodes, the current will only be able to run in one direction at a time. During the positive half og the cycle, the current will run clockwise through D1 (red arrows). In the negative half, the current will run counter-clockwise through D2 (green arrows). This is illustrated below
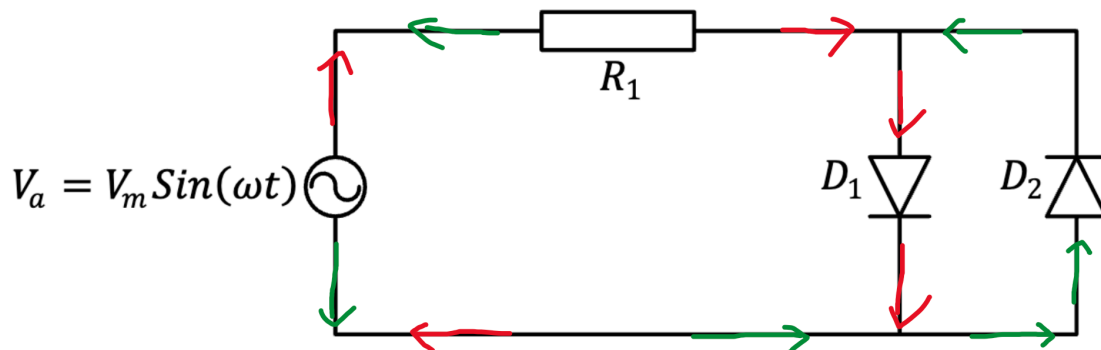


The current will only start running when the voltage surpasses $\pm V_{D,on}$. From that point, the forward voltage and currents follow a linear relationship proportional to R1
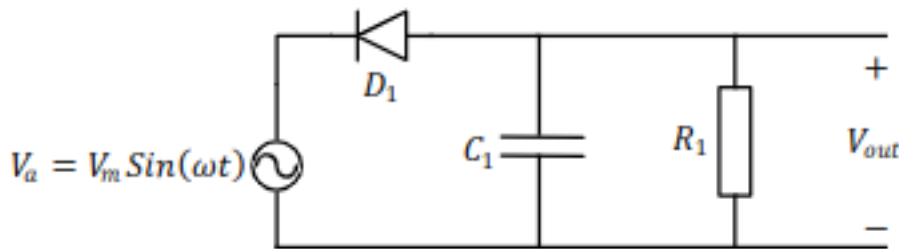
Problem 5) The 4 different circuits are analyzed individually:

Problem 5.1)
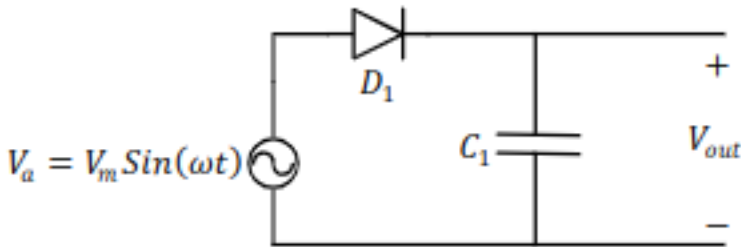


In this circuit, current can only flow when the top rail is positive compared to the bottom rail. This will charge the capacitor every cycle. The capacitor is not able to discharge at any point, so $V_{out}$ will increase every cycle to approach $V_m$

Problem 5.2)



Compared to the last circuit, the capacitor is now able to discharge over the resistor. During the positive cycle, the voltage will rise when the bottom rail is positive and fall when $V_a$ is lower than the capacitor voltage.

Problem 5.3)
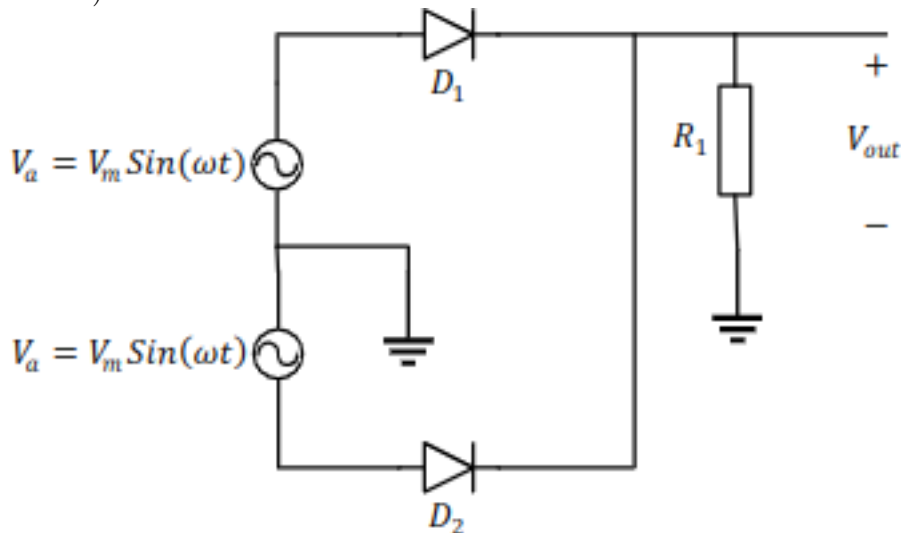


This center tapped full wave rectifier will turn make the voltage of positive during both halves of the cycle. In the first half, current can run through $D_1$ and $R_1$ into ground. In the other half, the current can run through $R_2$ instead. Since the power supply is center tapped, $V_{out}$ will only be half of $V_a - V_{d,on}$.

Problem 5.4)

$V_a = V_m Sin(\omega t)$
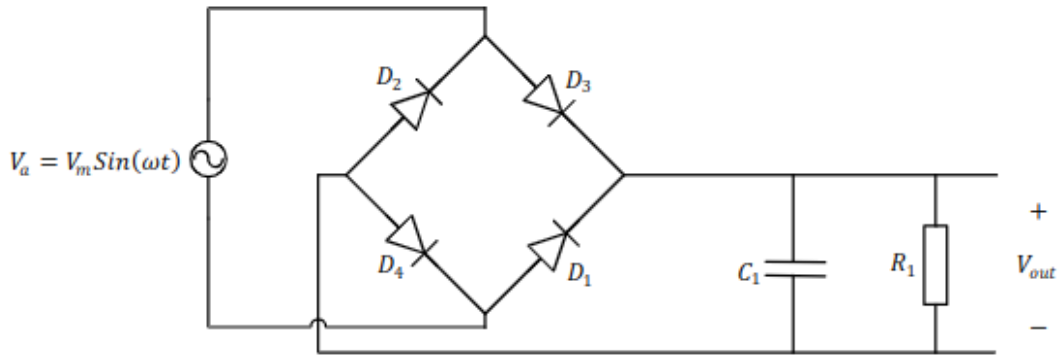
This full bridge rectifier will give the full voltage of $V_a$ turned positive. The capacitor will charge during both halves of the cycle as long as its voltage is higher than $|V_a|$ and discharge when it is lower. This smooths the rectified wave into a more constant voltage resembling DC.

Graphs)
The graphs showing $V_a$ (in black) and $V_{out}$ (in blue) over time for all 4 circuits can be seen here

5.1
$U_a$
$U_{out}$

5.2
$U_a$
$U_{out}$

5.3
$U_a$
$U_{out}$

5.4
$U_a$
$U_{out}$