Scilab Textbook Companion for High Voltage Engineering Theory and Practice by M. A. Salam, H. Anis, A. El Morshedy and R. Radwan[1]

Created by
Meenakshi Pundir
M.tech
Others
Vellore institute of Technology
College Teacher
None
Cross-Checked by
Reshma Konjari

July 17, 2017

[1]Funded by a grant from the National Mission on Education through ICT, http://spoken-tutorial.org/NMEICT-Intro. This Textbook Companion and Scilab codes written in it can be downloaded from the "Textbook Companion Project" section at the website http://scilab.in

Book Description

Title: High Voltage Engineering Theory and Practice

Author: M. A. Salam, H. Anis, A. El Morshedy and R. Radwan

Publisher: Marcel Dekker, NY

Edition: 2

Year: 2000

ISBN: 0-8247-0402-9

Scilab numbering policy used in this document and the relation to the above book.

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

AP Appendix to Example(Scilab Code that is an Appednix to a particular Example of the above book)

For example, Exa 3.51 means solved example 3.51 of this book. Sec 2.3 means a scilab code whose theory is explained in Section 2.3 of the book.

Contents

List of Scilab Codes

Chapter 2

Electric Fields

Scilab code Exa 2.8.5 calculate max field at sphere surface

```
//Example 5 // Ch 2
clc;
clear;
close;
// given data :
R=0.25; // in meter sphere radius
R1=0.75;//gap b/w two spheres in meters
S=1; // in meter is equal to R1+R2
S1=0.067; // in meter
S2=0.0048;
S3=0.01795;
S4=0.00128;
Epsilon_o=8.85*1e-12;
Q1 = %pi*Epsilon_o;

Q=Q1/(2*%pi*Epsilon_o);
Qp=S1*Q;
Qpp=S2*Q;
F1=Q/R^2+Qp/(R-S1)^2+Qpp/(R-S1)^2;

Qs=0.25*Q;
```

```
Qsp=0.01795*Q;
Qspp=0.00128*Q;
F2=Qs/(R1-S1)^2+Qsp/(R1-S1)^2+Qspp/(R1-S1)^2

E=F1+F2

printf("Max field at surface is %e V/m",E)
// NOTE: answer in the book is wrong as Q = Q1/2*%pi
    *Epsilon_o
```

Scilab code Exa 2.8.6 charge on each bundle max min and avg surface fields avg max

```
// Example 6 // Ch 2
clc;
clear;
close;
// given data
V=400*10^3; // applied voltage in kV
r_eq=0.08874; // equivalent radius in meters
H=12; // bundle height in meters
d=9; // pole to pole spacing in meters
Epsilon_o=8.85*10^-12;
x=sqrt((2*H)^2 + d^2);
Q = (V*2*%pi*Epsilon_o) / [(log(2*H/r_eq)) - log(x/d
    )];
q = Q/2;
printf("charge per bundle is %e C/m \n",Q)
printf("charge per subconductor is %e C/m \n",q)
r = 0.0175; //subconductor radius in meters
R = 0.45; //subconductor-to-subconductor spacing in
    meters
q = 2.44*1e-6; //charge per subconductor in C/m
d = 9; //in meters
Epsilon_o = 8.85*10^-12; //in F/m
x=[(1/r) + (1/R)];
```

```
y=[(1/r) - (1/R)];

Max = (q/(2*%pi*Epsilon_o))*(x); //maximum surface field in V/m
printf("maximum surface field is %e V/m \n ", Max)

Min = (q/(2*%pi*Epsilon_o))*[y]; //minimum surface field in V/m
printf("minimum surface field is %f V/m \n", Min)

Avg = (q/(2*%pi*Epsilon_o))*[1/r]; //average surface field in V/m
printf("average surface field is %f V/m \n", Avg)

E_01 = [(q/(2*%pi*Epsilon_o))*[1/r + 1/R]] - [(q/(2*%pi*Epsilon_o))*[1/(d+r)+1/(d+R+r)]];//field at outer point of subconductor in V/m
disp(E_01, "field at outer point of subconductor 1(V/m) =")
E_02 = [(q/(2*%pi*Epsilon_o))*[1/r + 1/R]] - [(q/(2*%pi*Epsilon_o))*[1/(d-R-r)+1/(d-r)]];
disp(E_02, "field at outer point of subconductor 2(V/m) =")
E_l1 = [(q/(2*%pi*Epsilon_o))*[1/r - 1/R] - (q/(2*%pi*Epsilon_o))*[1/(d-r)+1/(d+R-r)]];
disp(E_l1, "field at inner point of subconductor 1(V/m) =")
E_l2 = [(q/(2*%pi*Epsilon_o))*[1/r - 1/R] - (q/(2*%pi*Epsilon_o))*[1/(d-R-r)+1/(d+R)]];
disp(E_l2, "field at inner point of subconductor 2(V/m) =")
Avg = (E_01 + E_02)/2 // average maximum gradient in V/m
disp(Avg, "average maximum gradient is")

//answers in the book is wrong for subconductor 2, El1 and El2
```

Scilab code Exa 2.8.7 electric field induced at x equal to 1

```
// Example 7// Ch 2
clc;
clear;
close;
// given data
q = 1; // line charge in C/m
Epsilon_o=8.85*10^-12;
x1 = [1/3 + 1/7];//infinite sequence
x2 = [1 + 1/5 + 1/9];//infinite sequence
x3 = [1/5 + 1/9];//infinite sequence
E = (q/(2*%pi*Epsilon_o))*[1 - x1 + x2 + x3 - x1];
printf("total electric field is %e V/m",E)
// answer by this program is the round of value
```

Scilab code Exa 2.8.8 vol of insulator required for graded design

```
// Example 7// Ch 2
clc;
clear;
close;
// given data
z=10; //length of graded cylindrical bushing in cm
a=2; // radius of conductor inside bushing in cm
V=150; //AC voltage in kV
E_bd=50; // field strength in kV/cm
x0 = 2;
x1 = 6.24;
t_gd = V*sqrt(2)/E_bd;
printf("thickness of graded design is %f cm \n",
   t_gd)
```

```
zr = z*(t_gd + a);// bushing length must satisfy curve for the profile
printf("bushing length %f cm^2", zr)
V1 = integrate('4*%pi*zr','r',x0,x1);
printf("volume of graded design is %f cm^2 \n", V1)
t = 2*[exp(t_gd/2)-1];
printf("thickness of regular design is %f cm \n",t)
V2 = %pi*[(a + t)^2 - (a^2)];
printf("volume of regular design is %f cm^2 \n",V2)
// Note: There is caluclation error to find the volume of regular design.
// So answer in the book is wrong
```

Scilab code Exa 2.8.11 determine potentials within the mesh

```
//Example 11// Ch 2
clear all
clc
close

phi1=0;
phi3=10;

phir=[phi1;phi3];
sl=[1.25 -0.014;-0.014 0.8381]; //elements of global stiffness matrix
sr=-[-0.7786 -0.4571;-0.4571 -0.3667];//elements of global stiffness matrix

phil=inv(sl)*sr*phir

printf('value of potentials at the nodes are %f \n', phil)
```

Chapter 3

Ionization and Deionization Processes in gases

Scilab code Exa 3.7.1 speed of air molecules

```
// Example 1// Ch 3
clc;
clear;
close;
// given data
R=8314; // gas constant in J/kg.mol.K
T=300; // temperature 27 deg C, 27+293=300K
M=32; // oxygen is diatomic
v = sqrt(3*R*(T/M));
printf("speed of oxygen molecule %f m/s",v)
// Note: Value of R is given wrong in book
// So answer in the book is wrong
```

Scilab code Exa 3.7.2 total translational KE

```
// Example 2// Ch 3
```

```
clc;
clear;
close;
// given data
R=8314; // gas constant in J/kg.mol.K
T=298;//in kelvin
M=32; // oxygen is diatomic
m=2*10^-3; // in kg
p=1.01*10^5; // 1 atm=1.01*10^5 N/m2
G = (m*R*T)/(M*p);//volume of gas

x=(3/2)*p;//no. of molecules per unit volume where x
    =N*0.5*m*v^2 is given as (3/2)*p)
printf("volume of gas %e m^3 \n",G)
KE = x*G;//total translational kinetic energy
printf("total translational kinetic energy is %f J \
    n",KE)
// Note: Value of G is calculated in book is wrong
```

Scilab code Exa 3.7.3 max pressure in chamber

```
// Example 3// Ch 3
clc;
clear;
close;
// given data
R=8314; // gas constant in J/kg.mol.K
T=300; // temperature 27 deg C, 27+293=300K
me=0.10; //mean free path in meters
rm=1.7*10^-10 //molecular radius in angstrom
M=28 //im mole^-1
m0=4.8*10^-26 //mass of nitrogen molecule
N = 1/[4*%pi*((rm)^2)*me]; // no. of molecules in
    gas
printf("no. of molecules %e",N)
```

```
p = [(N*m0)/M]*R*T; // max pressure in chamber in N/m2
printf("max pressure in chamber %f N/m2",p)
// Note: Calculation in the book is wrong So answer in the book is wrong
```

Scilab code Exa 3.7.4 temperature at which avg KE of He atoms in gas become 1 eV

```
// Example 4// Ch 3
clc;
clear;
close;
// given data
v = 1.6*10^-19; // avg kinetic energy in j
k = 1.38*10^-23 //boltzmann constant in J/K
T = (2*v)/(3*k);
printf("temperature %e K",T)
```

Scilab code Exa 3.7.5 volume of 1 kg of He

```
// Example 6// Ch 3
clc;
clear;
close;
// given data
m = 1;//in kg
M=2.016;//molecular weight of helium
k = 8314// gas constant in J/kg.mol.K
p = 1.01*10^5;//1 atm=1.01*10^5 N/m2
T = 273;//in kelvin
G = m*k*T/(M*p);//volume of 1kg of helium in m^3
printf("volume of 1kg of helium is %f m^3",G)
```

Scilab code Exa 3.7.6 density of ions at dist equal to mfp and five times mfp

```
// Example 6// Ch 3
clc;
clear;
close;
// given data
z1=-1;//ion at a distance equal to mean free path, -
   x=mfp
z2=-5;//ion at a distance equal to five times the
   mean free path, -x=5mfp
//n0 is the density of ions at the origin
n1 = exp(z1);//density of ions at distance equal to
   the mean free path
n2 = exp(z2);//density of ions at distance equal to
   five times the mean free path
printf("density of ions at distance equal to the
   mean free path %fn0",n1)
printf("density of ions at distance equal to five
   times the mean free path %fn0",n2)
```

Scilab code Exa 3.7.7 mean square velocity of He atoms

```
// Example 7// Ch 3
clc;
clear;
close;
// given data
N = 178*10^-3 //gas density in kg/m^3
p = 1.01*10^5 //pressure
v = sqrt((3*p)/N); //mean square velosity of helium
   atoms
```

```
printf("mean square velosity of helium atoms %f m/s"
    ,v)
```

Scilab code Exa 3.7.8 energy of free electrons

```
//Example 8// Ch 3
clc;
clear;
close;
// given data
k = 1.38*10^-21; //boltzmanns constant
T = 293; // temperature in K
e = 1.6*10^-19;
E = (1.5*k*T)/e;
printf("energy of free electron %f eV",E)
```

Scilab code Exa 3.7.9 avg separation of atoms and avg vol occupied by one atom

```
//Example 9// Ch 3
clc;
clear;
close;
// given data
d = 0.075; //density of solid atomic hydrogen in g/
    cm^3
N_A = 6.0224*10^23; //1g of H consists of N_A atoms
N = N_A*d; // number of atoms/cm^3
printf("no. of atoms/cm^3 %e",N)
x = 1/N;//avg volume occupied by one atom in cm^3
y = (x)^(1/3);//avg seperation between atoms in cm
printf("avg vokume occupied by one atom %e cm^3",x)
printf("avg seperation between atoms %e cm",y)
```

Scilab code Exa 3.7.10 `KE in eV and velocity of phototelectron`

```
//Example 10// Ch 3
clc;
clear;
close;
// given data
l=200*10^-10;// wavelength in angstrom
h=4.15*10^-15;//planks constant
c=3*10^8;//speed of light
me=9.11*10^-31;
BE=13.6;//binding energy in eV
PE=(h*c)/l;//in eV
printf("photon enegy %f eV",PE)
KE = PE-BE;//in eV
printf("kinetic energy of photoelectron %f ev",KE)
ve=sqrt((2*KE*1.6*10^-19)/me);
printf("velosity of photoelectron %e m/s",ve)
```

Scilab code Exa 3.7.11 `liquid photon absorption coefficient`

```
//Example 11// Ch 3
clc;
clear;
close;
// given data
I = 1;
I0 = 6;
x=20;//in cm
u = -(1/x)*log(I/I0);
printf("absorption coefficient %f cm^-1",u)
```

Scilab code Exa 3.7.12 binding energy of the gas

```
//Example 12// Ch 3
clc;
clear;
close;
// given data
c=3*10^8;
h=4.15*10^-15;
lmax=1000*10^-10;
We=(c*h)/lmax;
printf("binding energy of gas %f eV",We)
```

Scilab code Exa 3.7.14 diameter of the argon atom

```
//Example 14// Ch 3
clc;
clear;
close;
// given data
p=1.01*10^5/760;// 1 torr in N/m2
k=1.38*10^-23;
T=273; //in Kelvin
n=85*10^2;//no of collisions per meter
N=p/(k*T);
printf("no of gas molecules %e atoms/m^3",N)
r_a=sqrt(n/(%pi*N*1));
printf("diameter of argon atom %e m",r_a)
```

Scilab code Exa 3.7.15 `mobility of electrons`

```
//Example 15// Ch 3
clc;
clear;
close;
// given data
Ie=3;//current flow in amperes
A=8*10^-4;//area of the electrodes in m^2
V=20;//voltage across the electrodes
d=0.8;//spacing between the electrodes in meters
n_e=1*10^17;//electron density in m^-3
e=1.6*10^-19;
ke=(Ie*d)/(A*V*n_e*e);
printf("mobility of electrons %f m^2/sV",ke)
```

Scilab code Exa 3.7.17 `ion density point 02 m away in both directions at 25 deg C`

```
//Example 17// Ch 3
clc;
clear;
close;
// given data
E = 5; //electric field in V/m
n_o = 10^11; //ion density in ions/m3
T = 293; // in kelvin
z = 0.02; //distance in meters
e = 1.6*10^-19; //in couloumb
k = 1.38*10^-23; // in m2 kg s-2 K-1
n1 = n_o*exp((-e*E*z)/(k*T));//ion density 0.02m away
n2 = n_o*exp((e*E*z)/(k*T));//ion density -0.02m away
printf("ion density 0.02m away %e ions/m^3 \n",n1)
printf("ion density -0.02m away %e ions/m^3 \n",n2)
```

Scilab code Exa 3.7.18 diameter of cloud after drifting a distance of point 05

```
//Example 18// Ch 3
clc;
clear;
close;
// given data
E = 250; //electric field in V/m
r1 = 0.3*10^-3//intial diameter of cloud in meters
k = 1.38*10^-23;//in m2 kg s-2 K-1
T = 293; //in kelvin
e = 1.6*10^-19;// in couloumb
z = 0.05;//drift distance in meters
r = (6*k*T*z)/(e*E);//diameter before drift
printf("diameter before drift %e m \n",r)
r2 = sqrt (r1^2 + r );//diamter after drifting a
    distance
printf("diameter after drift %e m \n",r2)
// round off value calculated for r and r2
```

Scilab code Exa 3.7.19 a mean free path of electrons in nitrogen and b ionization

```
//Example 19// Ch 3
clc;
clear;
close;
// given data
a = 9003;//constant in m-1kPa-1
B = 256584;//in V/m.kPa
p = 0.5;//in kPa
M = 1/(a*p);//mean free path in meters
```

```
printf("mean free path of electron in nitrogen %e m"
   ,M)
Vi = B/a; //ionization potential of nitrogen
printf("ionization potential of nitrogen %f V",Vi)
```

Chapter 4

Electrical Breakdown of Gases

Scilab code Exa 4.10.1 a alpha b no of electrons emitted from cathode per sec

```
//Example 1// Ch 4
clc;
clear;
close;
// given data
I1 = 2.7*10^-8;//steady state current in Amperes
V = 10; //voltage in kV
d1 = 0.005; //spacing between the plane electrodes
    in meters
d2 = 0.01; // spacing incresed in meters
I2 = 2.7*10^-7;//increased steady state current in
    amperes
e = 1.6*10^-19;
x = 1/(d2-d1);
y = log(I2/I1);
alpha = x*y;//ionization coefficient
printf("ionization coefficient %f m^-1",alpha)
I0 = I1*exp(-alpha*d1);//photoelctric current
printf("photoelectric current %e A",I0)
n0 = I0/e;
printf("no of electrons emitted from cathode %e
```

```
electrons/s",n0)
```

Scilab code Exa 4.10.2 electrode spacing

```
//Example 2// Ch 4
clc;
clear;
close;
// given data
I = 10^9;
alpha = 460.5;//ionization coefficient
d = log(I)/alpha;//electrode spacing in meter
printf("electrode spacing %f m",d)
```

Scilab code Exa 4.10.3 size of developed avalanche

```
//Example 3// Ch 4
clc;
clear;
close;
// given data
a=4*1e4;
b=15*1e5;
lb=0;
ub=0.0005;
i=integrate('(a-b*sqrt(x))','x',lb,ub)
as=exp(i);//Avalanche size
printf('Avalache size %f',as)
```

Scilab code Exa 4.10.4 distance it must travel to produce an avalanche

```
//Example 4// Ch 4
clc;
clear;
close;
// given data

a=7.5*1e5;
b=-4*1e4;
c=59.97;
p = poly([c, b,a], 'x', 'c');
alpha=roots(p);
printf('The distance it must travel to produce an
    avalanche of 1E9 electrons is (in m) %f',alpha(2)
    )
```

Scilab code Exa 4.10.5 `min distance measured from the cathode`

```
clear all
clc
close

a=7.5*1e5;
b=-4*1e4;
c=43.75;
p = poly([c, b,a], 'x', 'c');
alpha=roots(p);
printf('Minimum distance measured from the cathode
    at which an electron may start an avalanche
    having a size of 1E19 is (in m) %f',alpha(2))
```

Scilab code Exa 4.10.7 `total secondary coefficient of ionization at NTP`

```
//Example 7// Ch 4
```

```
clc;
clear;
close;
// given data
V = 9*10^3; //in V
d = 0.002;//two parallel plates spaced by distance d in meters
// 1/mean free path is equal to a*p where a is constant
s = 11253.7;//constant value in m^-1kPa^-1
B = 273840;//constant value in V/mkPa
p = 101.3;// in kPa
E = V/d;
t = (-B*p)/E;
alpha = p * s * exp(t);
printf("electric field %e V/m \n",E)
printf("ionization cofficient %f m^-1 \n",alpha)
z = 1/(exp(alpha*d)-1);//secondary coefficient of ionization
printf("secondary coefficient of ionization %f \n",z)
```

Scilab code Exa 4.10.8 cal the first ionization coefficient and the sec ionization

```
//Example 8// Ch 4
clc;
clear;
close;
// given data
//current between two parallel plates were 1.22,1.82,2.22 of the initiating photocurrent I1, I2, I3
x = 1.22;//x is I1/I0 I1=1.22I0
y = 1.82;//y is I2/I0 I2=1.82I0
w = 2.22;//z is I3/I0 I3=2.22I0
```

```
d1 = 0.005; //in meters
d2 = 0.01504; //in meters
d3 = 0.019; //in meters
// first ionization coefficients alpha1 , alpha2 and alpha3
alpha1 = log(x)/d1;
alpha2 = log(y)/d2;
alpha3 = log(w)/d3;
printf("first ionization coefficient %f m^-1 \n",alpha1)
printf("second ionization coefficient %f m^-1 \n",alpha2)
printf("third ionization coefficient %f m^-1 \n",alpha3)
// E/p and p were maintained constant so at d3 the secondary ionization coefficient mechanism must be acting without any change in alpha
z = (w - exp(alpha1*d3))/(w*(exp(alpha1*d3)-1));//secondary ionization coefficient
printf("secondary ionization coefficient %f \n",z)
```

Scilab code Exa 4.10.9 distance and voltage at the transition to a self sustained

```
//Example 9// Ch 4
clc;
clear;
close;
// given data
E = 1596; //in V/m
p = 0.133; //in kPa
a = E/p; // in V/m kPa kept constant as in example 8
alpha1 = 39.8;//from example 8
z = 0.0363; //from example 8
d = (1/alpha1)*[log(1/z + 1)];//distance at the transition to a self-sustained discharge
```

```
printf("distance at the transition to a self-sustained discharge %f m",d)
V = E*d;//voltage at the transition to a self sustained discharge
printf("Voltage at the transition to a self sustained discharge %f V",V)
```

Scilab code Exa 4.10.10 breakdown voltage

```
//Example 10// Ch 4
clc;
clear;
close;
// given data
d = 0.001; //in meters
p = 101.3; //in kPa
alpha = (17.7 + log(d))/d;//ionization coefficient in m^-1
x = alpha/p; //in m^-1kPa^-1
s = 11253.7; //constant in m-1kPa-1
B = 273840; //constant in V/m kPa
E1 = p/((-1/B)*log(x/s));// in V/m
Vs1 = E1*d; //break down voltage in V
printf("ionization coefficient %f m^-1 \n",alpha)
printf("electric field %e V/m \n",E1)
printf("breakdown voltage %f kV \n",Vs1*10^-3)
E2 = 468*10^4;// in V/m
Vs2 = E2*d;//breakdown voltage by meel and loeb's eq
printf("breakdown voltage %f kV \n",Vs2*10^-3)
```

Scilab code Exa 4.10.11 electron drift velocity and ionization coefficient

```
//Example 11// Ch 4
```

```
clc;
clear;
close;
// given data
d = 0.05; //electron current of an avalanche in
    uniform field gap of d in meters
t = 0.2*10^-6; //current decline abruptly in t sec
tc = 35*10^-9; //time constant
ve = d/t;//electron drift velocity in m/s
alpha = 1/(tc*ve);//townsend's ionization
    coefficient
printf("electron drift velocity %e m/s",ve)
printf("ionization coefficient %f m^-1",alpha)
```

Scilab code Exa 4.10.12 `a travel time of positive ions b max frequency`

```
//Example 12// Ch 4
clc;
clear;
close;
// given data
V = 200;//alternating voltage in kV(rms)
x = 0.1;//uniform gap in meters
f = 50;//frequency of voltage in Hz
k = 1.4*10^-4;//mobility of positive ions in m2/s.V
Ea = V*sqrt(2)*10^3/x;//alternating field in V/m
printf("alternating field %e V/m",Ea)
w = k*Ea/(2*%pi*f);
t = sinm(x/w)/314;
printf("travel time of positive ions from one
    electrode to other %f sec",t)
fmax = k*Ea/(2*%pi*x)
printf("maximum frequency that can be applied %f Hz"
    ,fmax)
```

Chapter 5

The Corona Discharge

Scilab code Exa 5.6.2 `breakdown voltage`

```
//Example 2// Ch 5
clc;
clear;
close;
// given data
d = 0.001;//in meters
p = 101.3; //gas pressure in kPa
C = -2400.4;//constant value
A = 0.027;//constant value
As = 10^8;//avalanche size
//secondary ionization coefficient is much smaller than unity therefore ionization coefficient (alpha) is equal to electron attachment coefficient
E = (2400.4*p)/0.027; //alpha is equal to e-attachment coeff occurs at this eq
Vs1 = E*d;//breakdown voltage in V
printf("electric field %e V/m \n",E)
printf("breakdown voltage %f V \n",Vs1)
Vs2 = (log(As)-C*p*d)/A; //in V
printf("breakdown voltage corresponding to an
```

```
avalanche size %f V \n",Vs2)
//as the avalanche self-space charge is neglected the breakdown voltage will be same irrespective of the polarity of the stressed plate acc. to eq (5.4) N2>=N1;
Vspos = 9.4;//in kV when N2>=N1 in which no of e- in second avalanche is greater than equal to no of e- in first avalanche
printf("positive voltage breakdown %f kV \n",Vspos)
Vsneg = 9.2;//in kV when Neph >= 1 where Neph is no of e-photoemitted from the cathode
printf("negative voltage breakdown %f kV \n",Vsneg)
```

Scilab code Exa 5.6.3 `repeat problem 2 for gas pressures of 3 and 5 atmospheres`

```
//Example 3// Ch 5
clc;
clear;
close;
// given data
d = 0.001;//in meters
p1 = 3*101.3; //gas pressure of 3 atmp in kPa
p2 = 5*101.3; //gas pressure of 5 atmp in kPa
C =  2400.4;//constant value
A = 0.027;//constant value
As = 10^8;//avalanche size
Vs1 = C*p1*d/A;//breakdown voltage at 3 atm
Vs2 = C*p2*d/A;//breakdown voltage at 5 atm
Vs3 = (log(As)+C*p1*d)/A;//breakdown voltage at 3 atm corresponding to an avalanche size
Vs4 = (log(As)+C*p2*d)/A;//breakdown voltage at 5 atm corresponding to an avalanche size
printf("breakdown voltage at 3 atm %f kV \n",Vs1*10^-3)
printf("breakdown voltage at 5 atm %f kV \n",Vs2
```

```
*10^-3)
printf("breakdown voltage at 3 atm corresponding to an avalanche size %f kV \n",Vs3*10^-3)
printf("breakdown voltage at 5 atm corresponding to an avalanche size %f kV \n",Vs4*10^-3)
//acc. to eq N2>=N1 and Neph>=1 with increase of gas pressure improves the dielectric strength of the gas since breakdown voltage increses with gas pressure
Vs1pos = 27.5;//postive breakdown voltage at 3 atm in kV
Vs1neg = 27.73;//negative breakdown voltage at 3 atm in kV
Vs2pos = 45.2;//postive breakdown voltage at 5 atm in kV
Vs2neg = 45.5;//negative breakdown voltage at 5 atm in kV
printf("positive breakdown voltage at 3 atm %f kV \n",Vs1pos)
printf("negative breakdown voltage at 3 atm %f kV \n",Vs1neg)
printf("positive breakdown voltage at 5 atm %f kV \n",Vs2pos)
printf("negative breakdown voltage at 5 atm %f kV \n",Vs2neg)
```

Scilab code Exa 5.6.5 `cal corona onset voltage`

```
//Example 5// Ch 5
clc;
clear;
close;
// given data
d=0.001;
a = 0.1*10^-2;//radii of concentric circle in meters
```

```
b = 2.1*10^-2;//radii of concentric circle in meters
p = 101.3;//gas pressure in kPa
p1=3*p;
p2=5*p;
C =  -2400.4;//constant value
A = 0.027;//constant value
As = 10^8;//avalanche size
ri = 0.0772;//in m
V0 = [log(10^8)-{(C*p)*(ri-a)}]*(b-a)/[A*{(1/a)-(1/
    ri)}];
printf("corona onset voltage is %f kV \n",V0)
V0pos = 13.1;//in kV
V0neg = 13.7;//in kV
printf("positive corona onset voltage %f kV \n",
    V0pos)
printf("negative corona onset voltage %f kV \n",
    V0neg)

//acc. to eq N2>=N1 and Neph>=1 with increase of gas
     pressure improves the dielectric strength of the
     gas since breakdown voltage increses with gas
    pressure
```

Scilab code Exa 5.6.6 for gas pressure of 3 and 5 atmp cal corona onset voltage

```
//Example 6// Ch 5
clc;
clear;
close;
// given data
d=0.001;
a = 0.1*10^-2;//radii of concentric circle in meters
b = 2.1*10^-2;//radii of concentric circle in meters
p = 101.3;//gas pressure in kPa
p1=3*p;
```

```
p2=5*p;
C =  -2400.4;//constant value
A = 0.027;//constant value
As = 10^8;//avalanche size
ri = 0.0772;//in m
V01 = [log(10^8)-{(C*p1)*(ri-a)}]*(b-a)/[A*{(1/a)-(1/ri)}];
V02 = [log(10^8)-{(C*p2)*(ri-a)}]*(b-a)/[A*{(1/a)-(1/ri)}];
printf("corona onset voltage at 3atmp is %f kV \n",V01)
printf("corona onset voltage at 5atmp is %f kV \n",V02)
V01pos = 41.9;//in kV at 3 atmp
V01neg = 42.2;//in kV at 3 atmp
V02pos = 69.2;//in kV at 5 atmp
V02neg = 69.8;//in kV at 5 atmp
printf("positive corona onset voltage %f kV \n",V01pos)
printf("negative corona onset voltage %f kV \n",V01neg)
printf("positive corona onset voltage %f kV \n",V02pos)
printf("negative corona onset voltage %f kV \n",V02neg)
//answer given in the book is wrong

//acc. to eq N2>=N1 and Neph>=1 with increase of gas pressure improves the dielectric strength of the gas since breakdown voltage increses with gas pressure
```

Scilab code Exa 5.6.8 Cal positive and negative corona onset voltages

```
//Example 8// Ch 5
```

```
clc;
clear;
close;
// given data

delta=1;//at standard temp and pressure
r=1;//radius of conductors in cm
s=40;//subconductor to subconductor spacing in cm
D=500; //phase to phase spacing in cm
E0=30*delta*(1+(0.3/sqrt(delta*r)));//corona onset
    field in kVpeak/cm
printf("corona onset field %f kVpeak/cm",E0)

V01=E0*log(D/r);//corona onset voltage using single
    conductor
printf("corona onset voltage V01 is %f kVpeak",V01)
V01rms=V01/sqrt(2);//rms onset voltage in kV
printf("corona rms onset voltage V01rms %f kV",
    V01rms)

x2 = log(D /(sqrt(s*r)));
y2 = (1+((2*r)/s));

V02=2*E0*r*(x2/y2);//corona onset voltage using
    bundle-2 conductor arranged horizontally and
    vertically
printf("corona onset voltage V02 is %f kVpeak",V02)
V02rms=V02/sqrt(2);//rms onset voltage in kV
printf("corona rms onset voltage V02rms is %f kV",
    V02rms)


x3 = log(D /((sqrt(2)*(s)^2*r)^0.3));
y3 = (1+((3*sqrt(3)*r)/s));

V03=3*E0*r*(x3/y3);//corona onset voltage using
    bundle-3 conductor arranged at vertices of an
    upright or inverted triangle
```

```
printf("corona onset voltage V03 is %f kVpeak",V03)
V03rms=V03/sqrt(2);//rms onset voltage in kV
printf("corona rms onset voltage V03rms is %f kV",V03rms)


x4 = log(D /((sqrt(2)*(s)^3*r)^0.25));
y4 = (1+((4*sqrt(2)*r)/s));

V04=4*E0*r*(x4/y4);//corona onset voltage using bundle-4 conductor arranged at vertices of a square
printf("corona onset voltage V04 is %f kVpeak",V04)
V04rms=V04/sqrt(2);//rms onset voltage in kV
printf("corona rms onset voltage V04rms is %f kV",V04rms)


x5 = log(D /((sqrt(2)*(s)^3*r)^0.25));
y5 = (1+((3*sqrt(2)*r)/s));

V05=4*E0*r*(x5/y5);//corona onset voltage using bundle-4 conductor arranged at vertices of a diamond form square
printf("corona onset voltage V05 is %f kVpeak",V05)
V05rms=V05/sqrt(2);//rms onset voltage in kV
printf("corona rms onset voltage V05rms is %f kV",V05rms)

//acc. to eq 5.18 in question 7 corona onset voltage is calculated
```

Scilab code Exa 5.6.9 `cal corona onset voltage at standard temperature and pressur`

```
//Example 9// Ch 5
```

```
clc;
clear;
close;
// given data
Deq=600;//mean geometric distance b/w conductors in
    cm
delta=1;//at standard temp and pressure
r=1;//radius of conductors in cm
E0=30*delta*(1+(0.3/sqrt(delta*r)));//corona onset
    field in kVpeak/cm
printf("corona onset field %f kVpeak/cm",E0)
V0=E0*log(Deq);//corona onset voltage
printf("corona onset voltage %f kVpeak",V0)
V0rms=V0/sqrt(2);//rms onset voltage in kV
printf("corona rms onset voltage %f kV",V0rms)
```

Scilab code Exa 5.6.10 `cal corona power loss and corona current`

```
//Example 10// Ch 5
clc;
clear;
close;
// given data
m1=0.92;//smoothness coefficient
m2=0.95;//weather coefficient
Deq=600;//mean geometric distance b/w conductors in
    cm
V = 275;//line operating at voltage V in kV
p=75;//pressure in cm Hg
t = 35;//in degree C
r=1;//radius of conductors in cm
delta=3.92*p/(273+t);//relative air density
printf("relative air density %f",delta)
E0=30*delta*(1+0.3/sqrt(delta*r))*m1*m2;//corona
    onset field
```

```
printf("corona onset field %f kVpeak/cm",E0)
V0 = E0*log(Deq);//onset voltage in kVpeak
printf("onset voltage %f kVpeak",V0)
V0rms=V0/sqrt(2);//rms onset voltage
printf("rms onset voltage %f kV",V0rms)
V0ll=V0rms*sqrt(3);//onset voltage line to line
printf("line to line onset voltage %f kV line to line",V0ll)
K= 0.05;
f=50;//in Hz
Vph=(V*10^3)/sqrt(3);
Pc=3.73*K*f*(Vph^2)*10^-5/(Deq/r)^2;
printf("corona power loss %f kW/(cond.km)",Pc)
Ic=Pc/Vph;
printf("corona current %e A/km",Ic)
```

Scilab code Exa 5.6.11 `cal corona onset voltage and the effective radius of the co`

```
//Example 10// Ch 5
clc;
clear;
close;
// given data
m1=0.9;//smoothness coefficient
m2=0.9;//weather coefficient
r=3.175;//radius of conductor in cm
V=525;//rated voltage in kV where no corona is present
delta=1;//relative air-density factor
Deq=112.63;//in cm
E0=30*delta*(1+0.3/sqrt(delta*r))*m1*m2;//corona onset field
printf("corona onset field %f kVpeak/cm",E0)
E0rms=E0/sqrt(2);
printf("rms corona onset field %f kV/cm",E0rms)
```

```
V0=E0*r*log(Deq);
printf("corona onset voltage %f kV",V0)
V0ll=V0*sqrt(3);
printf("corona onset voltage lin to line %f kV",V0ll
   )
V1=2.5*V;//line to line voltage higher than V0 so
   corona is present on the conductor
re=5;//effective radius of corona envelope in cm
printf("envelope radius %f cm",re)
```

Chapter 12

High Voltage Cables

Scilab code Exa 12.17.1 radial thickness and operating voltage

```
//Example 1// Ch 12
clc;
clear;
close;
// given data
r1=2;//inner coaxial cable radius
r2=5;//sheath radius over the insulation
Em1=40;//max stress in the insulation in kV/cm
Em2=25;//max stress in the insulation in kV/cm
epsilon1=6;
epsilon2=4;
x=Em1/Em2;
r=x*((epsilon1*r1)/(epsilon2));//radial thickness of the dielectric
printf("radial thickness of the dielectric %f cm",r)
inner=r-r1;//inner thickness of dielectric
outer=r2-r;//outer thickness of dielectric
printf("inner thickness of dielectric %f cm",inner)
printf("outer thickness of dielectric %f cm",outer)
V1=Em1*r1*log(r/r1);//voltage drop across dielectric in kV
```

```
V2=Em2*r*log(r2/r);//voltage drop across outer dielectric
printf("voltage drop across dielectric %f kV",V1)
printf("voltage drop across outer dielectric %f kV",V2)
pv = V1+V2;//peak voltage of cable
printf("peak voltage of cable %f kV",pv)
pvrms=pv/sqrt(2);
printf("peak voltage in rms %f kV",pvrms)
```

Scilab code Exa 12.17.2 `value of conductor radius optimum value of r`

```
//Example 2// Ch 12
clc;
clear;
close;
// given data
V=100;//in kV
Em=55;//max permissible gradient in kV/cm
//voltage gradient at the conductor surface is inversely proportional to the core radius
r=V*sqrt(2)/Em;//conductor radius in cm
printf("conductor radius %f cm",r)
```

Scilab code Exa 12.17.3 `resistivity of insulating material`

```
//Example 3// Ch 12
clc;
clear;
close;
// given data
l=10*10^3;//core cable length in m
Res=0.5;//insulation resistance in Mohms
```

```
R=1.5;//core diameter in cm
R1=3;//sheath diameter in cm
resistivity=Res*2*%pi*l/log(R1/R);
printf("resistivity of the material %e Mohms.m",
   resistivity )
```

Scilab code Exa 12.17.4 KVAr

```
//Example 4// Ch 12
clc;
clear;
close;
// given data
l=10;//length of cable in km
C4=0.5*10^-6 * l;//in F
printf("Capacitance %f F",C4)
f=50;//in Hz
V=10^4;//in V
Ic=2*V*2*%pi*f*C4/sqrt(3);//line charging current in
    A
chargKVA=sqrt(3)*V*Ic*10^-3;
printf("charging KVA %f KVAr",chargKVA)
```

Scilab code Exa 12.17.5 capacitance per km the KVAr

```
//Example 5// Ch 12
clc;
clear;
close;
// given data
C2 = 0.75/3;//capacitance between 3 core bunched
   together and lead sheath in uF/km
C3=0.56//in uf/km
```

```
V=33*10^3;
f=50;//in Hz
C4=0.5*(C2+C3)*10;//capacitance per km b/w any two
    cores
printf("capacitance per km b/w any two cores %f uF",
    C4)
ChargKVAr=V^2*2*%pi*f*C4/10^9;
printf("Charging KVAr %f KVAr",ChargKVAr)
//given ans in book is wrong the capacitance of 10km
    b/w 2 cores is 4.05uF
```

Scilab code Exa 12.17.6 effective electrical parameters

```
//Example 6// Ch 12
clc;
clear;
close;
// given data
l=85;//in km
r=1;//core cables of conductore radius r in cm
f=50;//in Hz
Rex=3.0;//external radii in cm
Rin=2.5;//internal radii in cm
Rac=0.0875;//conductor AC resistance in ohms/km
rest=23.2*10^-6;//resistivity of lead in ohms cm
tc=0.004;//temperature coefficient
Rc=Rac*(1+tc*f)*l;//conductor resistance in ohms
Rsh=rest*l*10^5/(%pi*(Rex^2-Rin^2));
printf("conductor resistance %f ohms",Rc)
printf("resistance of sheath %f ohms",Rsh)
rsh=0.5*(Rin+Rex);//mean radius of sheath
D=8;//cable to cable spacing in cm
Xm=2*%pi*f*2*log(D/rsh)*10^-7*l*10^3;//conductor to
    sheath mutual inductive reactance for 85km length
printf("inductive reactance %f ohms",Xm)
```

```
Ref=Rc+(Xm^2*Rsh)/(Rsh^2+Xm^2);//effective AC
    resistance of conductor
printf("effective resistance %f ohms",Ref)
Xc=11.1;//resistance with sheaths open ckt in ohms
Xef=Xc-(Xm^2)/(Rsh^2+Xm^2);//effective reactance per
    cable
printf("effective reactance per cable %f ohms",Xef)
s=Rsh*(Xm^2)/(Rc*(Rsh^2 + Xm^2));//sheath loss to
    conductor loss
printf("sheath loss to conductor loss %f",s)
I=400;//current in A
emf=I*Xm;//emf induced without bonding per sheath in
    V
printf("emf induced %f V",emf)
```

Scilab code Exa 12.17.7 induced sheath voltage per km

```
//Example 7// Ch 12
clc;
clear;
close;
// given data
D=15;//conductor spacing in cm
rsh=2.75;//sheath radius in cm
I=250;//current in A
f=50;//in Hz
Xm=2*%pi*f*2*log(D/rsh)*10^-7*10^3;//conductor to
    sheath mutual inductive reactance
E=I*Xm;//indused sheath field in V/km
printf("indused sheath field %f V/km",E)
E1=sqrt(3)*E;//voltage b/w sheaths when bonded at
    one end
printf("voltage b/w sheaths when bonded at one end
    %f V/km",E1)
```

Scilab code Exa 12.17.8 max stress and best position and voltage on the intersheat

```
//Example 8// Ch 12
clc;
clear;
close;
// given data
a=2;
b=5.3;
alpha=(b/a)^0.33;
r1=1.385;//radii of intersheaths in cm
r2=1.92;//radii of intersheaths in cm
r=1;//conductor radius in cm
ri=2.65;//sheath of inside radius in cm
V=66;//voltage in kv
Vpeak=66*sqrt(2)/sqrt(3);//peak voltage
V2=Vpeak/(1+1/alpha+(1/alpha)^2);//in kV
V1=(1+1/r1)*V2;//in kV
printf("%f kV",V2)
printf("%f kV",V1)
Emax0=Vpeak/(r*log(ri/r));
printf("max stress without sheaths %f kV/cm",Emax0)
Emin0=Vpeak/(ri*log(ri/r));
printf("min stress without sheaths %f kV/cm",Emin0)
Emax=3*Emax0/(1+alpha+alpha^2);
printf("max stress %f kV/cm",Emax)
Emin=Emax/alpha;
printf("min stress %f kV/cm",Emin)
```

Scilab code Exa 12.17.9 find voltage at max stress and find max stress

```
//Example 9// Ch 12
```

```
clc;
clear;
close;
// given data
V = -18.2;//in kV
V1 = 45.2;//in kV
V2 = 23;//in kV

E1max = 2.28*(V-V1);//max stress in layers
E2max = 2.12*(V1-V2);//max stress in layers
E3max = 2.06*V2;//max stress in layers

// as E1max=E2max=E3max=Emax
Emax = 2.06*V2;
printf("max stress is %f kV",Emax)
```

Scilab code Exa 12.17.10 max stress in rubber and in paper

```
//Example 10// Ch 12
clc;
clear;
close;
// given data
a=1;//inner thickness of cable in cm
epsilonr1=4.5;
epsilonr2=3.6;
r1=2;//in cm
b=2.65;//in cm
V=53.8;//in kV
Emax1=V/(a*[log(r1)+(epsilonr1/epsilonr2)*log(1.325)
   ]);
printf("max stress in rubber %f kV/cm",Emax1)
Emax2=V/(r1*[((epsilonr2/epsilonr1)*log(r1))+ log
   (1.325)]);
printf("max stress in paper %f kV/cm",Emax2)
```

Chapter 16

High voltage generation

Scilab code Exa 16.7.1 `ripple voltage voltage drop avg output voltage and ripple f`

```
clear all
clc
close

iload=5*1e-3;//Load current in A

//Capacitances of Cockcroft-Waltobn type voltage doubler in F
C1=0.01*1e-6;
C2=0.05*1e-6;

f=50;//frequency in Hz
Vs=100*1e3//Supply voltage in V

//Ripple voltage in volt
dv=iload/(C2*f)
printf('Ripple voltage in V %f',dv)

//Voltage drop in Volt
Vdrop=iload/f*(1/C1+1/(2*C2))
printf('Voltage drop in V %f',Vdrop)
```

```

//Average output voltage
V_av=2*sqrt(2)*Vs-Vdrop//in V
printf('Avarage voltage in V %f',V_av)

//Ripple factor
RF=Vdrop/(2*sqrt(2)*Vs)*100//in percentage
printf('Ripple voltage in percentage %f',RF)
```

Scilab code Exa 16.7.2 `ripple voltage voltage drop avg output voltage and ripple f`

```

clear all
clc
close

iload=5*1e-3;//Load current in A

//Capacitances of Cockcroft-Waltobn type voltage tripler in F
C1=0.01*1e-6;
C2=0.05*1e-6;
C3=0.10*1e-6;

f=50;//frequency in Hz
Vs=100*1e3//Supply voltage in V

//Ripple voltage in V
dv=iload/f*(2/C1+1/C3)
printf('Ripple voltage in V %f',dv)

//Voltage drop in V
Vdrop=iload/f*(1/C2+1/C1+1/(2*C3))
printf('Voltage drop in V %f',Vdrop)

```

```
//Average output voltage in V
V_av=3*sqrt(2)*Vs-Vdrop
printf('Avarage voltage in V %f',V_av)

//Ripple factor in percentage
RF=Vdrop/(3*Vs*sqrt(2))*100
printf('Ripple voltage in percentage %f',RF)
```

Scilab code Exa 16.7.3 ripple voltage voltage drop avg output voltage ripple facto

```
clear all
clc
close

Vs=200*1e3//Supply voltage
f=50//Frequency in Hz
n=12//Number of stages

C=0.15*1e-6//Each stage capacitance in F
iload=5*1e-3//Load current in A

//Ripple voltage in V
dv=iload/(f*C*2)*n*(n+1)
printf('Ripple voltage in V %f',dv)

//Voltage drop in V
Vdrop=iload/(f*C)*(2*n^3/3+n^2/2-n/6+n*(n+1)/4)
printf('Voltage drop in V %f',Vdrop)

//Average output voltage in V
V_av=2*n*sqrt(2)*Vs-Vdrop
printf('Avarage voltage in V %f',V_av)

//Ripple factor in percentage
RF=Vdrop/(2*n*Vs*sqrt(2))*100
```

```
printf('Ripple voltage in percentage %f',RF)

//Otimum number of stages
nopt=sqrt(sqrt(2)*f*C*Vs/iload)
printf('Optimum number of stgaes for minimum voltage drop %f',int(nopt))
```

Scilab code Exa 16.7.4 `find the inductance and input voltage and power to the tran`

```
clear all
clc
close

f=50;//Power frequency
xl=8/100;//leakage reactance
r=3.5/100;//resistance
Vc=500;//Charging voltage in kV
Ic=4;//Charging current in A
capc=100;//kVA rating of transformer
vhigh=250;//Voltage rating of secondary of transformer in kV
vlow=220;//Voltage rating of primary of transformer in V

//Reactance of cable in kiloohm
Xc=Vc/Ic

//Leakage recatance of transformer in kiloohm
XL=xl*(vhigh^2/capc)

//Additional series inductance
xh=Xc-XL;

//Inductance of the required series inductor in Henry
```

```
L=xh/(2*%pi*f)*1e3;
printf('Inductance of the required series inductor in %f  Henry \n',L)

//Total circuit resistance in kiloohm
R=r*(vhigh^2/capc)

//The maxium current can be supplied by transformer in A
I=capc/vhigh;

Vsec = I*R;
printf("exciting voltage on the transformer secondary %f kV \n",Vsec)

//Exciting voltage of secondary of transformer in kV
Vexsec=I*R;

//Input voltage to primary of transformer in V
Vin=Vexsec*1e3*vlow/(vhigh*1e3);
printf('Input voltage to primary of transformer in %f V \n',Vin)

//Input power to transformer in kW
Pin=Vin*capc/vlow
printf('Input power to primary of transformer in %f kW \n',Pin)
```

Scilab code Exa 16.7.5 charging current and the potential difference between dome

```
clear all
clc
close

u=10//speed of belt in m/s
```

```
w=0.1//width of the belt in m
rhos=0.5*1e-6//surface charge density on the belt in
    C/m^2
Rleak=1e14//Resistanc ein ohm

//Charging current in A
I=rhos*u*w
printf('Charging current in uA %f',I*1e6)

//Potentail difference between the dome and the base
    in V
V=I*Rleak
printf('Potentail difference between the dome and
    the base in MV is %f',V/1e6)
```

Scilab code Exa 16.7.6 `wave eq parameters and wave generated`

```
clear all
clc
close

C1=0.125*10^-6;//in Farad
C2=1*10^-9;//in Farad
R1=360;//in ohms
R2=544;//in ohms
theta = sqrt(C1*C2*R1*R2);//in usec
n = 1/[1+(1+(R1/R2))*(C2/C1)];
alpha = (R2*C1)/(2*theta*n);
printf("theta parameter of wave eq %f us \n",theta
    *10^6)
printf("n the parameter of circuit eq %f \n",n)
printf("alpha parameter of circuit eq %f \n",alpha)
T2 = 10.1*theta;//duration of lightning impulse
    pulse in us
T1 = T2/45;//duration of lightning impulse pulse in
```

```
us
printf("duration of lightning impulse pulse %f us \n",T2*10^6)
printf("duration of lightning impulse pulse %f us \n",T1*10^6)
//answer in the book for T1 is wrong

T = T1/T2;
printf("generated lighting impulse is %f us \n",T)
alpha1 = [alpha-sqrt((alpha^2)-1)]/theta;//in us^-1
alpha2 = [alpha+sqrt((alpha^2)-1)]/theta;//in us^-1
printf("aplha1 parameter of wave eq is %f us^-1 \n",alpha1*10^-6)
printf("aplha1 parameter of wave eq is %f us^1 \n",alpha2*10^-6)

//answer in the book is slightly different
// Now eq of waveform of generated pulse is e(t)=99.75(e^-0.015t - e^-2.77t)
```

Scilab code Exa 16.7.7 wave eq parameters and wave generated

```
clear all
clc
close

C1=0.125*10^-6;//in Farad
C2=1*10^-9;//in Farad
R1=360;//in ohms
R2=544;//in ohms
theta = sqrt(C1*C2*R1*R2);//in usec
n = 1/[1+(R1/R2)+(C2/C1)];
alpha = (R2*C1)/(2*theta*n);
printf("theta parameter of wave eq %f us \n",theta*10^6)
```

```
printf("n the parameter of circuit eq %f \n",n)
printf("alpha parameter of circuit eq %f \n",alpha)
T2 = 16.25*theta;//duration of lightning impulse pulse in us
T1 = T2/120;//duration of lightning impulse pulse in us
printf("duration of lightning impulse pulse %f us \n",T2*10^6)
printf("duration of lightning impulse pulse %f us \n",T1*10^6)
//answer in the book for T1 is wrong

T = T1/T2;
printf("generated lighting impulse is %f us \n",T)
alpha1 = [alpha-sqrt((alpha^2)-1)]/theta;//in us^-1
alpha2 = [alpha+sqrt((alpha^2)-1)]/theta;//in us^-1
printf("aplha1 parameter of wave eq is %f us^-1 \n",alpha1*10^-6)
printf("aplha1 parameter of wave eq is %f us^1 \n",alpha2*10^-6)

// Now eq of waveform of generated pulse is e(t)=60.2(e^-0.0088t - e^-4.62t)
```

Scilab code Exa 16.7.8 wave shaping resistors R1 and R2 and also circuit efficienc

```
clear all
clc
close

//Elements of circuits
C1=0.125*1e-6;//in F
C2=1e-9;//in F

T1=250*1e-6;
```

```
T2=2500*1e-6;
alpha=4;
theta=T2/6;

X=(1+C2/C1)*1/alpha^2;
R1=alpha*theta/C2*(1-sqrt(1-X));//in ohm

R2=alpha*theta/(C1+C2)*(1+sqrt(1-X));//in ohm

//Circuit efficiency
eta=1/(1+(1+R1/R2)*C2/C1)
printf('Circuit efficiency %f',eta)
```

Scilab code Exa 16.7.9 values of wave shaping resistors and max output voltage and

```
clear all
clc
close

n=8;//no ofstage
C1=0.16*1e-6;//Each stage capacitor in F
C2=1e-9;//Load capacitance in F
T2=50*1e-6;
T1=1.2*1e-6;
Vch=120;//Charging voltage in kV

//Total capacitance in F
CT=C1/n;

alpha=6.4;
theta=T2/9.5;

X=(1+C2/C1)/alpha^2;
R1=alpha*theta/C2*(1-sqrt(1-X));//in ohm

```

```
R2=alpha*theta/(CT+C2)*(1+sqrt(1-X));//in ohm
//Perstage shaping resistance in ohm
printf('Perstage shaping resistance in %f ohm',R1/n)

Vdc=n*Vch;
eta=1/(1+(1+R1/R2)*C2/CT)

//Maximum output voltage
Vmax=eta*Vdc;
printf('Maxium output voltage in %f kV',Vmax)

//Energy rating in J
E=0.5*CT*(Vdc*1e3)^2;
printf('Energy rating in %f J',E)
```

Scilab code Exa 16.7.10 find front and tail times of the lightning impulse produce

```
clear all
clc
close

n=12;//no ofstage
C1=0.125*1e-6;//Each stage capacitor in F
C2=1000e-12;//Load capacitance in F
R1=70;//Front resistance in ohm
R2=400;//Tail resistance in ohm

R1T=R1*n;
R2T=R2*n;
C1T=C1/n;

theta=sqrt(C1T*C2*R1T*R2T);

eta=1/(1+(1+R1T/R2T)*C2/C1T);

```

```
alpha=R2T*C1T/(2*eta*theta);

//Wavetail time in us
T2=7*theta*1e6;
printf('Wave tail time in us %f',T2)

//Wave front time in us
T1=T2/25;
printf('Wave front time in us %f',T1)
```

Scilab code Exa 16.7.11 parameters and eq for generated impulse current

```
clear all
clc
close

C = 8*10^-6;//in Farad
L = 8*10^-6;//in Henry
V = 25*10^3;//in V
T1 = 8;//in us time for the first peak
ohmega = 0.02*10^-6;//in sec^-1
R = sqrt((4*L/C)-(4*L^2*ohmega^2));
printf("resistance is %f ohms \n",R)
gama = R/(2*L);//in sec^-1
printf("parameter gama is %f sec^-1 \n",gama)

//Now eq for generated impulse pulse is I(t)=
    156.25*10^3exp(-12.3*10^4t)sin(0.02*10^6t)A
```

Chapter 19

Applications of high voltage engineering in industry

Scilab code Exa 19.18.1 `determine separation between the particles after falling 1`

```
clear all
clc
close

qm=10*1e-6;//q/m ratio in C/kg
E=8*1e5;//Electric field in V/m
g=9.8;//Universal gravitational constant

y=-1;//in meters
t=sqrt(-2*y/g);

//Calculation of separation distance between particles
x=(qm*E*t^2)/2;
printf('Distance of separation between particles in %f m',2*x)
```

Scilab code Exa 19.18.2 cal pumping pressure

```
clear all
clc
close

rho=30*1e-3;//Charge density in C/m^3
Vo=30*1e3;//Voltage in V

//Calculation of pumping pressure
P=Vo*rho;
printf('Pumping pressure is %f N/m^2',P)
```

Scilab code Exa 19.18.4 find vertical displacement of the drop on the print surfac

```
clear all
clc
close

dia=0.03*1e-3;//Diameter of drop in m
rho=2000;//Desnity of ink in kg/m
vz=25;//velocity in z direction in m/sec
L1=15*1e-3;//Length of deflection plate in m
L2=12*1e-3;//distance from the exit end of the
    deflection plate to the print surface in m
q=100*1e-15;//Charge of drop in C
d=2*1e-3;//Spacing in m
Vo=3500;//Charging voltage in V

//Mass of drop in kg
m=(4/3)*%pi*rho*(dia/2)^3;

to=L1/vz;
vxo=q*Vo*to/(m*d);
xo=0.5*vxo*to;
```

```
t1=(L1+L2)/vz;
printf("time required for the drop to reach the print surface is %f s \n",t1)

//Calculation of vertical displacement of the drop on the print surface in mm
x1=xo+vxo*(t1-to);
printf('Vertical displacement of the drop on the print surface is %f m \n',x1)
```

Scilab code Exa 19.18.5 electric stress and charge density on the microphone elecr

```
clear all
clc
close

epsr=2.8;//Dielectric constant of plastic
epso=8.84*1e-12;//Permittivity of air in F/m
rho_s=25*1e-6;//Surface charge in C/m^3
a=25*1e-6;//Thickness of palstic in m
b=75*1e-6;//distance in m

//Calculation of electric stress in the foil/plastic laminate in MV/m
Ea=b*rho_s/(a*epso+b*epso*epsr)
printf('Electric stress Ea in the foil/plastic laminate in %f MV/m \n',Ea/1e6)

Eb=a*rho_s/(a*epso+b*epso*epsr);
printf("field inside the electret %f V/m \n",Eb)
//Calculation of charge desnity in uC/m^2
rho_sc=epso*Eb;
printf('Calculation of charge desnity in %f uC/m^2 \n',rho_sc*1e6)
```

Scilab code Exa 19.18.6 space charge limited current density and current density a

```
clear all
clc
close

epso=8.84*1e-12;//Permittivity of air in F/m
mui=1.5*1e-4;//Mobility in m^2/sec.V
V=100;//Applied voltage in V
d=0.01;//Distance between two parallel plates in m
mus=0.001*mui;//Miobility of charged smoke particles

//Calculation of current density in nA/m^2
J=4*epso*mus*V^2/d^3;
printf('Calculation of current density in %f nA/m^2'
   ,J*1e9)
```

Scilab code Exa 19.18.7 thickness of the layer

```
clear all
clc
close

epso=8.84*1e-12;//Permittivity of air in F/m
rho=15*1e-3;//Charge density in C/m^3
Ebd=3*1e6;//Breakdown voltage in V/m

//Thickness of dust layer in mm
dbd=Ebd*epso/rho
printf('Thickness of dust layer is %f mm',dbd*1e3)
```

Scilab code Exa 19.18.8 velocity of the ejected ions and propulsion force

```
clear all
clc
close

mi=133*1.67*1e-27;//Mass of cesium in kg
qi=1.6*1e-19;//Charge in C
Va=3500;//Accelerating voltage in V
I=0.2;//Ion current in A

//Calculation of velocity of ejected ions in km/s
vi=sqrt(2*qi*Va/mi);
printf('Velocity of ejected ions is %f m/s',vi)

//Calculation of propulsion force in mN
F=vi*mi*I/qi
printf('propulsion force is %f N',F)
```

Scilab code Exa 19.18.9 position of the particle at the exit end of the plate

```
clear all
clc
close

V = 120*10^3;//voltage b/w collecting parallel
    plates in V
d=0.6;//in meters
y1=1.2;//vertical dimension of the plates in m
cm = 10*10^-6;//charge to mass ratio in C/kg
g =-9.8;//gravitational force
```

```
//intergrating -9.8t with initial conditions we obtain y = -4.9t^2
y = 4.9;//at t=y0
t0 = sqrt(y1/y);
printf("phosphate particle exit plate at %f sec",t0)
EF = (cm*V)/d;//velosity of particle in x direction is governed by electrostatic force
printf("electrostatic force %f m/s^2",EF)
//integrating twice and subsituting initial conditions we have x = t^2; t=t0
x=(t0)^2;
printf("particle exits the plate at %f m",x)
```

Scilab code Exa 19.18.10 minimum voltage required to generate a charge

```
clear all
clc
close

a=25*10^-6;//jet radius in m
b=750*10^-6;//concentric cylinder of radius
q=50*10^-12;//charge
l = 120*10^-6;//length of jet inside the cylinder
Epsilon_o = 8.84*10^-12;
C=(2*%pi*Epsilon_o*l)/log(b/a);
printf("capacitance is %e F",C)
r=50*10^-6;//drop radius
Vp = (3*a^2*log(b/a)*q)/(8*%pi*Epsilon_o*r^3);
printf("min voltage required for generating drops %f kV",Vp/1e3)
```