```
close all
clear
clc
load('constants.mat')
e=1.60217733e-19;
K=menu('Choose a task','1','2.1','2.2','2.3','2.4');


if (K==1)
    N=1000;
    P=10;
    x=linspace(-10*pi,10*pi, N);
    fc=@(P,x)cos(x)+P*sin(x)./x;

    figure('Units','normalized','OuterPosition',[0 0 1 1])
    subplot(2,1,1)
    plot(x,ones(1,N),'k--');
    hold on;
    grid on;
    plot(x,-1*ones(1,N),'k--');
    ylim([-10;10]);
    xlim([x(1),x(N)]);
    title(['$P = ', num2str(P),'$'],'Interpreter','latex')
    xlabel('$a\alpha$','Interpreter','latex')
    ylabel('$cos(a\alpha)+P*{sin(a\alpha)\over(a
\alpha)}$','Interpreter','latex')

    Xmin=x(1);
    syms xx real
    x1=vpasolve(cos(xx)+sin(xx)/xx==1,xx,[-10*pi;10*pi]);
    x2=vpasolve(cos(xx)+sin(xx)/xx==-1,xx,[-10*pi;10*pi]);
    X1=double(x1);
    X2=double(x2);

    stepz=50;
    X(1)=X1;
    dx=(x(N)-x(1))/stepz;
    for n = 1:stepz
        diap=[Xmin+dx*(n-1),Xmin+n*dx];
        x1=vpasolve(cos(xx)+P*sin(xx)/xx==1,xx,diap);
        x2=vpasolve(cos(xx)+P*sin(xx)/xx==-1,xx,diap);
        if(~isempty(x1))
            if(double(x1)~=X1)
                X1=double(x1);
                X=[X X1];
            end
        end
        if(~isempty(x2))
            if(double(x2)~=X2)
                X2=double(x2);
                X=[X X2];
            end
```

```
        end
    end

    for i=1:length(X)/2
        %shader(@(x)1,@(x)-1,X(2*i),X(2*i+1),0.1,pi/4,'--k')
        fill([X(2*i-1),X(2*i-1),X(2*i),X(2*i)],[-1 1 1 -1], [0.9 0.9
 0.9])
    end
    plot(x,fc(P,x));

    subplot(2,1,2)
    P=0;
    plot(x,ones(1,N),'k--');
    hold on;
    grid on;
    plot(x,-1*ones(1,N),'k--');
    ylim([-10;10]);
    xlim([x(1),x(N)]);
    title('$1.$ $P=0$','Interpreter','latex')
    xlabel('$a\alpha$','Interpreter','latex')
    ylabel('$cos(a\alpha)+P*{sin(a\alpha)\over(a
\alpha)}$','Interpreter','latex')

    fill([x(1),x(1),x(N),x(N)],[-1 1 1 -1], [0.9 0.9 0.9])
    plot(x,fc(P,x));
%elseif K==2
    n=[10 20 30];
    a=@(x)0.56533+0.00078*x;    a=a(0)*1e-9;
    m=@(x)(0.067+0.083*x)*m0;   m=m(0);

    Psi=@(q,a,x)abs(mod(q,2)*cos(pi*q/a*x)+(mod(q+1,2))*sin(pi*q/
a*x)).^2;
    E=@(q,a)hbar^2/(2*m)*(q*pi/a)^2/e;

    x=linspace(-1e-9,1e-9);
    figure('Units','normalized','OuterPosition',[0 0 1 1])
    subplot(3,2,1)
    hold on;
    grid on;
    plot(x,Psi(1,n(1)*a,x));
    plot(x,Psi(2,n(1)*a,x));
    plot(x,Psi(3,n(1)*a,x));
    plot(x,Psi(4,n(1)*a,x));
    legend('n=1','n=2','n=3','n=4')
    xlabel('$x,m$','Interpreter','latex')
    ylabel('$\Psi$','Interpreter','latex')
    title('$a=10*a_0$','Interpreter','latex')

    subplot(3,2,2)
    hold on;
    grid on;
    plot([0 1],[1 1]*E(1,n(1)*a));
    plot([0 1],[1 1]*E(2,n(1)*a));
    plot([0 1],[1 1]*E(3,n(1)*a));
```

```
    plot([0 1],[1 1]*E(4,n(1)*a));
    legend('n=1','n=2','n=3','n=4')
    ylabel('$E,eV$','Interpreter','latex')
    title('$a=10*a_0$','Interpreter','latex')
    ylim([0 3]);

    subplot(3,2,3)
    hold on;
    grid on;
    plot(x,Psi(1,n(2)*a,x));
    plot(x,Psi(2,n(2)*a,x));
    plot(x,Psi(3,n(2)*a,x));
    plot(x,Psi(4,n(2)*a,x));
    legend('n=1','n=2','n=3','n=4')
    xlabel('$x,m$','Interpreter','latex')
    ylabel('$\Psi$','Interpreter','latex')
    title('$a=20*a_0$','Interpreter','latex')

    subplot(3,2,4)
    hold on;
    grid on;
    plot([0 1],[1 1]*E(1,n(2)*a));
    plot([0 1],[1 1]*E(2,n(2)*a));
    plot([0 1],[1 1]*E(3,n(2)*a));
    plot([0 1],[1 1]*E(4,n(2)*a));
    legend('n=1','n=2','n=3','n=4')
    ylabel('$E,eV$','Interpreter','latex')
    title('$a=20*a_0$','Interpreter','latex')
    ylim([0 3]);

    subplot(3,2,5)
    hold on;
    grid on;
    plot(x,Psi(1,n(3)*a,x));
    plot(x,Psi(2,n(3)*a,x));
    plot(x,Psi(3,n(3)*a,x));
    plot(x,Psi(4,n(3)*a,x));
    legend('n=1','n=2','n=3','n=4')
    xlabel('$x,m$','Interpreter','latex')
    ylabel('$\Psi$','Interpreter','latex')
    title('$a=30*a_0$','Interpreter','latex')

    subplot(3,2,6)
    hold on;
    grid on;
    plot([0 1],[1 1]*E(1,n(3)*a));
    plot([0 1],[1 1]*E(2,n(3)*a));
    plot([0 1],[1 1]*E(3,n(3)*a));
    plot([0 1],[1 1]*E(4,n(3)*a));
    legend('n=1','n=2','n=3','n=4')
    ylabel('$E,eV$','Interpreter','latex')
    title('$2.1$ $a=30*a_0$','Interpreter','latex')
    ylim([0 3]);
%elseif K==3
```

```
    N=menu('Choose a width','10a','20a','30a');
    m=@(x)(0.067+0.083*x)*m0;
    a=@(x)0.56533+0.00078*x;    a=a(0)*1e-9;
    mb=m(0);
    ma=m(0.3);
    n=[10 20 30];

    U0=0.364*e;
    %E0=[0.0236 0.09266 0.18521]*e;
    a=n(N)*a;

    bt=@(E)sqrt(2*mb*(U0-E))/hbar;
    gm=@(E)sqrt(2*ma*E)/hbar;

    A1=@(a,E)3;
    A2=@(a,E)A1(a,E)*0.5*(1-1i*bt(E)/gm(E)*ma/mb)*exp((1i*gm(E)-
bt(E))*a/2);
    B2=@(a,E)A1(a,E)*0.5*(1+1i*bt(E)/gm(E)*ma/mb)*exp(-
(1i*gm(E)+bt(E))*a/2);
    B3=@(a,E)A1(a,E)*0.5*((1-1i*bt(E)/gm(E)*ma/
mb)*exp(1i*gm(E)*a)+(1+1i*bt(E)/gm(E)*ma/mb)*exp(-1i*gm(E)*a));

    Psi1=@(z,a,E)A1(a,E)*exp(bt(E)*z);
    Psi2=@(z,a,E)A2(a,E)*exp(1i*gm(E)*z)+B2(a,E)*exp(-1i*gm(E)*z);
    Psi3=@(z,a,E)B3(a,E)*exp(-bt(E)*z);

    fA=@(E) [exp(-bt(E)*a/2), -exp(-1i.*gm(E)*a/2), -
exp(1i.*gm(E)*a/2), 0;
    bt(E)/mb.*exp(-bt(E)*a/2), -1i.*gm(E)/ma.*exp(-1i.*gm(E)*a/2),
 1i*gm(E)/ma.*exp(1i.*gm(E)*a/2), 0;
    0, exp(1i.*gm(E)*a/2), exp(-1i.*gm(E)*a/2), -exp(-bt(E)*a/2);
    0, 1i*gm(E)/ma.*exp(1i.*gm(E)*a/2), -1i.*gm(E)/
ma.*exp(-1i.*gm(E)*a/2), bt(E)/mb.*exp(-bt(E)*a/2)];

    E=0:1e-5:0.2;
    A=arrayfun(fA, E*e, 'un', 0);
    D=cellfun(@(x) sqrt(det(x)*conj(det(x))),A);

    TF = islocalmin(D); %#### ############, ############ #######
 islocalmin
    Es=E(TF)*e;

    z=linspace(-a,a,500);
    U=zeros(1,100);
    Psi=zeros(1,100);
    Max=0;

    for j=1:length(Es)
        for i=1:length(z)
            if(z(i)<=-a/2)
                U(i)=U0;
                Psi(j,i)=Psi1(z(i),a,Es(j));
            elseif(z(i)>=a/2)
                U(i)=U0;
```

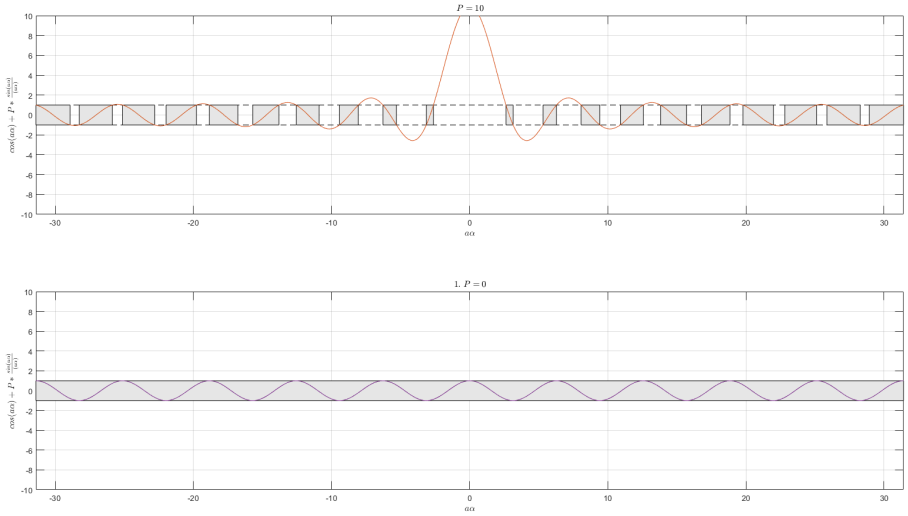
```
                Psi(j,i)=Psi3(z(i),a,Es(j));
            else
                U(i)=0;
                Psi(j,i)=Psi2(z(i),a,Es(j));
            end
            if(Max<Psi(j,i))
                Max=Psi(j,i);
            end
        end
    end

    figure('Units','normalized','OuterPosition',[0 0 1 1])
    grid on
    hold on
    for i=1:length(Es)
        plot(z,Psi(i,:).^2)
    end
    plot(z,U/U0*Max^2,'--r')
    xlabel('$Coordinaate,m$','Interpreter','latex')
    ylabel('$\Psi$','Interpreter','latex')
    title('$2.2Quantum$ $well$','Interpreter','latex')

%elseif K==4
    x=0.4;
    m=@(x)(0.067+0.083*x)*m0;
    a=@(x)(0.56533+0.00078*x);    a=20*1e-9;
    mb=m(0);
    ma=m(x);

    U0=1.247*0.4/2*e;

    gm1=@(E)sqrt(2*ma*E)/hbar;
    gm2=@(E)sqrt(2*mb*(E-U0))/hbar;

    A1=@(E)0.08;
    B1=@(E)A1(E)*(gm1(E)-gm2(E))./(gm1(E)+gm2(E));
    A2=@(E)A1(E)*2*gm1(E)/(gm1(E)+gm2(E));

    psi1=@(z,E)A1(E)*exp(1i*gm1(E)*z)+B1(E)*exp(-1i*gm1(E)*z);
    psi2=@(z,E)A2(E)*exp(1i*gm2(E)*z);


    E=[0.01 0.15 0.23 U0/e 0.32 0.35]*e;
    Z=real(2*sqrt(2*mb*(U0-E)));
    z=linspace(-a,a,1e3);
    L=length(z);
    Psi=zeros(5,L);
    for j=1:length(E)
         Psi(j,1:L/2)=psi1(z(1:L/2),E(j));
         Psi(j,L/2+1:L)=psi2(z(L/2+1:L),E(j));
         if Z(j)~=0
             Z(j)=hbar/Z(j);
         end
    end
```

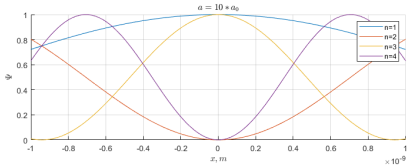
```
    Psi=Psi.*conj(Psi);

    figure('Units','normalized','OuterPosition',[0 0 1 1])
    subplot(1,2,1)
    grid on
    hold on
    for i=1:length(E)
        plot(z,E(i)/e+Psi(i,:));
        plot([z(1),z(L)],[E(i) E(i)]/e,'--
k','HandleVisibility','off');
        if(Z(i)~=0)
            plot([Z(i) Z(i)],[E(i)/e-0.01 E(i)/e+0.01],'-
dk','HandleVisibility','off')
            text(Z(i)+5e-10, E(i)/e-0.005,['x_e = ',+
 num2str(round(Z(i)*1e11)/100),+'nm']);
        end
    end
    plot(z,[zeros(1,L/2) ones(1,L/2)]*U0/e,'-.r','LineWidth',2)
    xlabel('$Coordinaate,m$','Interpreter','latex')
    ylabel('$\Psi$','Interpreter','latex')
    title('$2.3$ $Quantum$ $step$','Interpreter','latex')
    legend('E1','E2','E3','E4','E5')

    E=linspace(0, 1,L)*e;
    D=4*abs(gm1(E).*gm2(E))./abs(gm1(E)+gm2(E)).^2.*heaviside(E-U0);
    %D=gm2(E)./gm1(E)*ma/mb.*abs(A2(E)).^2/abs(A1(E)).^2;
    R=abs(gm1(E)-gm2(E)).^2./abs(gm1(E)+gm2(E)).^2;

    subplot(1,2,2);
    grid on
    hold on
    plot(E/e,D,'k')
    plot(E/e,R,'--k')
    plot(E/e,R+D,':k')
    plot([E(1)/e E(L)/e],[1/exp(1) exp(-1)],'HandleVisibility','off')
    legend('D','R','D+R');
    xlabel('$Energy,eV$','Interpreter','latex')
    ylabel('$R,D$','Interpreter','latex')
    title('$2.3$ $Quantum$ $step$','Interpreter','latex')
%elseif K==5
    m=@(x)(0.067+0.083*x)*m0;
    a=@(x)(0.56533+0.00078*x)*1e-9;
    Eg=@(x) e*(1.424+1.247*x).*heaviside(0.45-x)+...
            e*(1.9+0.125*x+0.143*x.^2).*heaviside(x-0.45);
    N=20;

                x=0.3;
    x1=0;       x2=x;       x3=0;
    m1=m(x1);   m2=m(x2);   m3=m(x3);
    a=N*a(x);

    U1=Eg(x1)/2;
    U2=Eg(x2)/2;
```

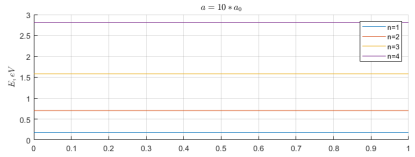
```
    U3=Eg(x3)/2;

    z=linspace(-a,1.5*a,500);
    Len=length(z);
    U0=heaviside(-z)*U1+heaviside(z).*heaviside(a-z)*U2+heaviside(z-
a)*U3;

    gm1=@(E)sqrt(2*m1*(E-U1))/hbar;
    gm2=@(E)sqrt(2*m2*(E-U2))/hbar;
    gm3=@(E)sqrt(2*m3*(E-U3))/hbar;

    xsi=@(E)(gm1(E)/m1+gm2(E)/m2).*(gm2(E)/m2+gm3(E)/
m3).*exp(1i*(gm3(E)-gm2(E))*a)+...
            (gm1(E)/m1-gm2(E)/m2).*(gm2(E)/m2-gm3(E)/
m3).*exp(1i*(gm3(E)+gm2(E))*a);

    A1=@(E)0.2;
    A3=@(E)4*gm1(E)/m1.*gm2(E)/m2*A1(E)./xsi(E);
    A2=@(E)(gm2(E)./m2+gm3(E)./m3)./(2*gm2(E)./m2)*exp(1i*(gm3(E)-
gm2(E))*a).*A3(E);
    B2=@(E)(gm2(E)./m2-gm3(E)./m3)./(2*gm2(E)./
m2)*exp(1i*(gm3(E)+gm2(E))*a).*A3(E);
    B1=@(E)A2(E)+B2(E)-A1(E);

    D=@(E)heaviside(E-U1).*(gm3(E)./gm1(E)*m3/m1.*abs(A3(E)).^2./
abs(A1(E).^2));

    E1=0.5*e; E2=1.5*e; N=5e2;
    dE=(E2-E1)/N;
    Ei=E1+(1:N)*dE;

    Emax=Ei(islocalmax(D(Ei)));
    Emin=Ei(islocalmin(D(Ei)));
    En=[0.72 0.88 0.8]*e;

    figure('Units','normalized','OuterPosition',[0 0 1 1])
    subplot(2,3,[1 2 3])
    grid on
    hold on
    plot(Ei/e,D(Ei))
    xlabel('$Energy,eV$','Interpreter','latex')
    ylabel('$R,D$','Interpreter','latex')
    title('$2.4$ $Quantum$ $barrier$','Interpreter','latex')
    plot(Emax/e,D(Emax),'ob')
    plot(Emin/e,D(Emin),'hr')
    ylim([0 1.05])

    psi1=@(z,E)A1(E)*exp(1i*gm1(E)*z)+B1(E)*exp(-1i*gm1(E)*z);
    psi2=@(z,E)A2(E)*exp(1i*gm2(E)*z)+B2(E)*exp(-1i*gm2(E)*z);
    psi3=@(z,E)A3(E)*exp(1i*gm3(E)*z);

    Psimin=zeros(length(Emin),Len);
    Psimax=zeros(length(Emax),Len);
    Psi=zeros(length(En),Len);
```

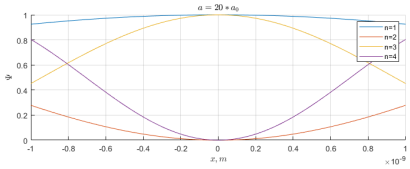
```
for j=1:length(Emax)
    for i=1:Len
       if(z(i)<=0)
           Psimax(j,i)=psi1(z(i),Emax(j));
       elseif(z(i)>0 && U0(i)>=U2)
           Psimax(j,i)=psi2(z(i),Emax(j));
       else
           Psimax(j,i)=psi3(z(i),Emax(j));
       end
    end
end

 for j=1:length(Emin)
    for i=1:Len
       if(z(i)<=0)
           Psimin(j,i)=psi1(z(i),Emin(j));
       elseif(z(i)>0 && U0(i)>=U2)
           Psimin(j,i)=psi2(z(i),Emin(j));
       else
           Psimin(j,i)=psi3(z(i),Emin(j));
       end
    end
 end

 for j=1:length(En)
    for i=1:Len
       if(z(i)<=0)
           Psi(j,i)=psi1(z(i),En(j));
       elseif(z(i)>0 && U0(i)>=U2)
           Psi(j,i)=psi2(z(i),En(j));
       else
           Psi(j,i)=psi3(z(i),En(j));
       end
    end
end

Psimax=Psimax.*conj(Psimax);
Psimin=Psimin.*conj(Psimin);
Psi=Psi.*conj(Psi);

subplot(2,3,4)
grid on
hold on
for j=1:length(Emin)
    plot(z*1e9,Psimin(j,:)+(Emin(j))/e)
end
xlabel('$x, nm$','Interpreter','latex')
ylabel('$|\Psi|^2$','Interpreter','latex')
title('$\Psi^2 (E_{min})$','Interpreter','latex')
plot(z*1e9,(U0)/e,'--k')
%ylim([0 1.05])
xlim([z(1)*1e9 z(Len)*1e9])
```

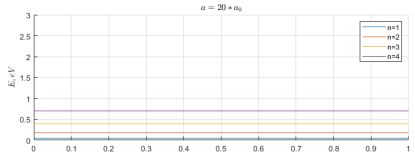
```
    subplot(2,3,5)
    grid on
    hold on
    for j=1:length(En)
        plot(z*1e9,Psi(j,:)+(En(j))/e)
    end
    xlabel('$x, nm$','Interpreter','latex')
    ylabel('$|\Psi|^2$','Interpreter','latex')
    title('$\Psi^2 (E<U)$','Interpreter','latex')
    plot(z*1e9,(U0)/e,'--k')
    %ylim([0 1.05])
    xlim([z(1) z(Len)]*1e9)

    subplot(2,3,6)
    grid on
    hold on
    for j=1:length(Emax)
        plot(z*1e9,Psimax(j,:)+(Emax(j))/e)
    end
    xlabel('$x, nm$','Interpreter','latex')
    ylabel('$|\Psi|^2$','Interpreter','latex')
    title('$\Psi^2 (E_{max})$','Interpreter','latex')
    plot(z*1e9,(U0)/e,'--k')
    %ylim([0 1.05])
    xlim([z(1)*1e9 z(Len)*1e9])

end
```

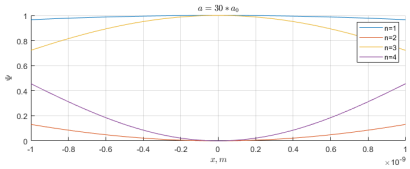


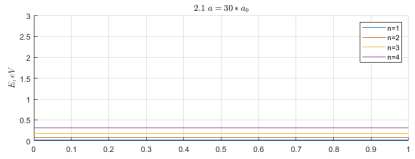

$a = 10 * a_0$
n=1
n=2
n=3
n=4
Ψ
x, m
$\times 10^{-9}$

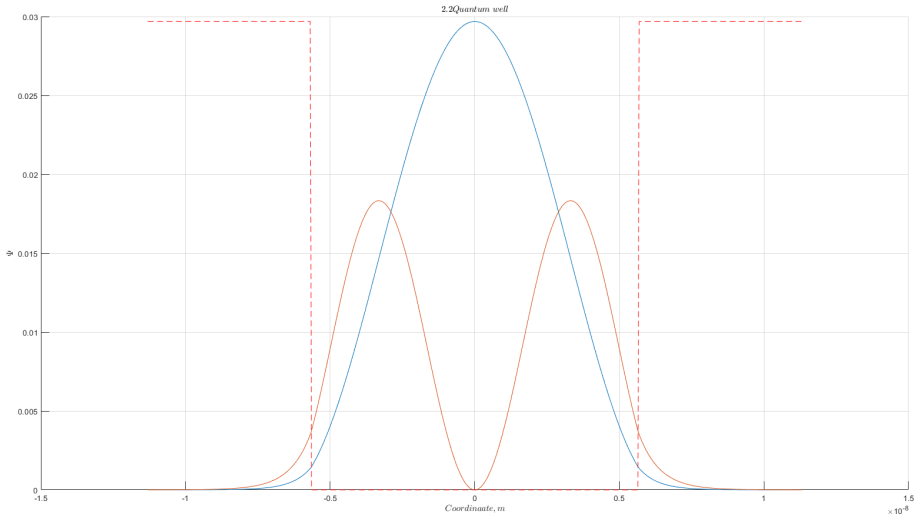

$a = 10 * a_0$
n=1
n=2
n=3
n=4
E, eV

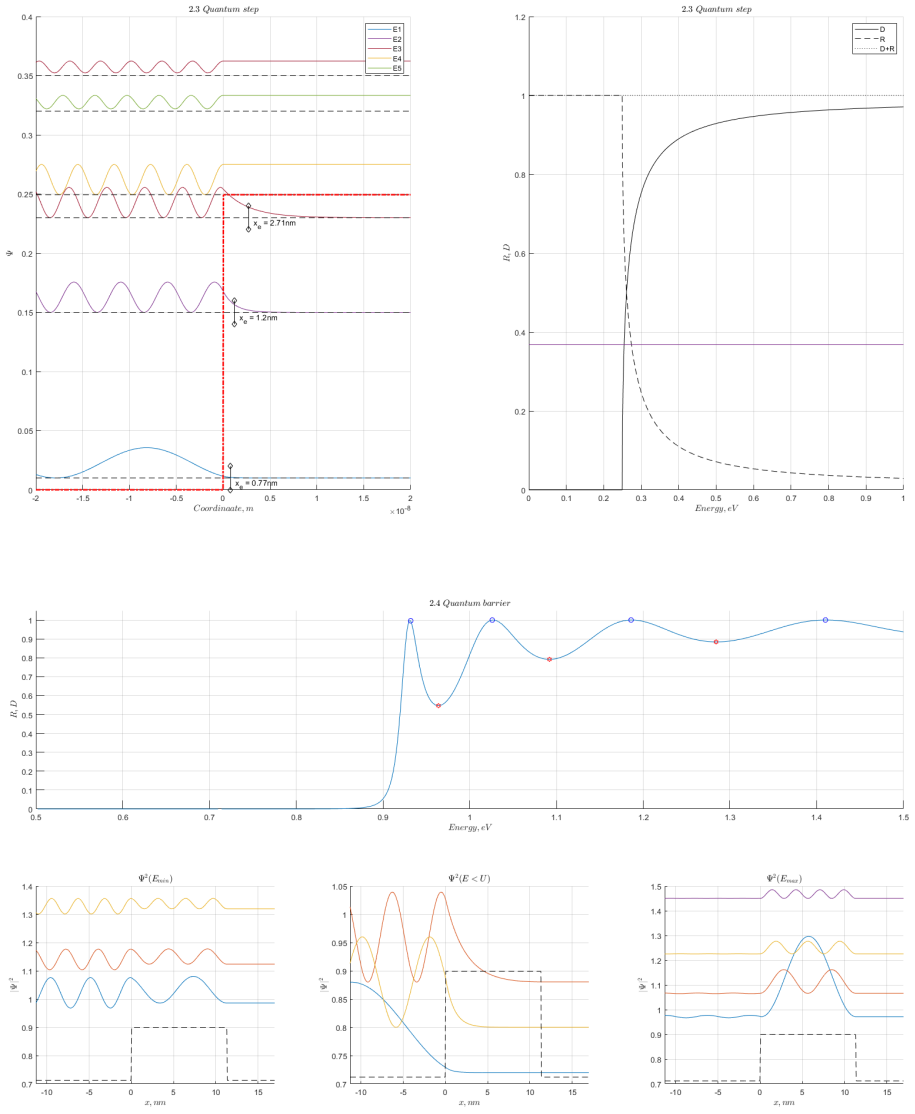

$a = 20 * a_0$
n=1
n=2
n=3
n=4
Ψ
x, m
$\times 10^{-9}$


$a = 20 * a_0$
n=1
n=2
n=3
n=4
E, eV


$a = 30 * a_0$
n=1
n=2
n=3
n=4
Ψ
x, m
$\times 10^{-9}$


2.1 $a = 30 * a_0$
n=1
n=2
n=3
n=4
E, eV


2.2Quantum well
Ψ
$Coordinate, m$
$\times 10^{-8}$



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