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Roll No.: 2020PHY116

QUANTUM MECHANICS
(LAB)

SEMESTER - V

ASSIGNMENT - 9

2020PHY1116

Ans 1

(a) The time-independent S.E.:

$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m} \nabla^2 \Psi + V \Psi$$
$$= H \Psi$$

In spherical coordinates;

$$\nabla^2 = \frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2}{\partial \phi^2}$$

So our Time Independent SE can be written as:

$$-\frac{\hbar^2}{2m} \left[\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial \Psi}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial \Psi}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 \Psi}{\partial \phi^2} \right] + \cancel{V} = [E - V] \Psi$$

(b) Let

$$\Psi(r, \theta, \phi) = R(r) Y(\theta, \phi)$$

$$\begin{aligned}
 & \frac{\hbar^2}{2m} \left[\frac{Y}{f^2} \frac{d}{df} \left(f^2 \frac{dR}{df} \right) + \frac{R}{f^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial Y}{\partial \theta} \right) \right. \\
 & \quad \left. + \frac{R}{f^2 \sin^2 \theta} \frac{\partial^2 Y}{\partial \phi^2} \right] \\
 & = RY [E - V(f)] Y
 \end{aligned}$$

$$\textcircled{D} \quad \frac{1}{R} \frac{d}{df} \left(f^2 \frac{dR}{df} \right) - \frac{2mY^2}{\hbar^2} [V(f) - E] = -\frac{1}{Y} LY$$

$$\text{where } L = \frac{1}{\sin \theta \partial \theta} \left(\sin \theta \frac{\partial}{\partial \theta} \right) + \frac{1}{\sin^2 \theta} \frac{\partial^2}{\partial \phi^2}.$$

Separating the radial & angular part of equation :

$$\frac{d}{df} \left(f^2 \frac{dR}{df} \right) - \frac{2mY^2}{\hbar^2} [V(f) - E] R = l(l+1)R$$

$$\frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial Y}{\partial \theta} \right) + \frac{1}{\sin^2 \theta} \frac{\partial^2 Y}{\partial \phi^2} = -l(l+1)Y$$

(c) We originally wrote Schrödinger Eq in
polar coordinates as for radial part:

$$\left[-\frac{\hbar^2}{2m} \frac{d^2}{dr^2} + \frac{\hbar^2 \lambda(\lambda+1)}{2m r^2} - \frac{e^2}{r} \right] X_{nl}(\lambda) = E_{nl} X_{nl}(\lambda) \quad (1)$$

$$V_{\text{eff}}(\lambda) = -\frac{e^2}{r} + \frac{\hbar^2}{2m} \frac{\lambda(\lambda+1)}{r^2}$$

effective Potential

Let $f = \frac{r}{a_0}$ \rightarrow Bohr Radius

Eq ① becomes:

$$\left[-\frac{\hbar^2}{2m} \frac{1}{a_0^2} \frac{d^2}{df^2} + \frac{\hbar^2 \lambda(\lambda+1)}{2m a_0^2 f^2} - \frac{e^2}{a_0 f} - E_{nl} \right] X_{nl}(a_0 f) = 0$$

Let $U_{nl}(f) = X_{nl}(a_0 f)$

$$\left[\frac{d^2}{df^2} - \frac{\lambda(\lambda+1)}{f^2} + \frac{2}{f} - \frac{e^2}{a_0 f} \right] U_{nl}(f) = 0$$

$$\left[\frac{d^2}{dr^2} - \frac{l(l+1)}{r^2} + \frac{2\mu e^2 \alpha_0}{\cdot r^2} \frac{1}{\bar{P}} + \frac{2\mu a_0^2}{r^2} E_{nl} \right] u_{nl}(r) = 0$$

$$\left[\frac{d^2}{dr^2} - \frac{l(l+1)}{r^2} + \frac{2}{\bar{P}} - \frac{l(l+1)}{r^2} \right] u_{nl}(r) = 0$$

~~Eqn~~ $V_{\text{eff}}(r) = \frac{\hbar^2 l(l+1)}{2m_e r^2} - \frac{e^2}{r \epsilon_0}$

first term: is the Centripetal potential related to $\frac{1}{r^2}$

Second term: is Coulomb potential, related to $-\frac{1}{r}$

When $l \neq 0$ (i.e. ^{not} s -orbital), centripetal potential is dominant, i.e. electrons of p , d , f orbitals are far from nucleus than e^- of s -orbital ($l=0$).

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+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01

2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013584e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237678e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016596e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
4.93049014e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 7 -0.
01562703662654502
energy eigen vector for n= 7 [-2.98604997e+00 -7.
78588339e-01 -3.48957395e-01 -1.96526724e-01
-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520854e+00 2.55492898e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00

5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809713e
+00 9.91131801e+00
1.05695461e+01 1.12421038e+01 1.19283007e
+01 1.26274342e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602384e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e
+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013584e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237678e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016596e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
4.93049014e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01

5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 8 -0.
012347066577112459
energy eigen vector for n= 8 [-2.98604997e+00 -7.
78588339e-01 -3.48957395e-01 -1.96526724e-01
-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520855e+00 2.55492898e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809713e
+00 9.91131801e+00
1.05695461e+01 1.12421038e+01 1.19283007e
+01 1.26274342e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602384e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e
+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013584e
+01 3.43487830e+01

3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237678e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016596e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
4.93049015e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 9 -0.
009989095574055112
energy eigen vector for n= 9 [-2.98604997e+00 -7.
78588339e-01 -3.48957395e-01 -1.96526724e-01
-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520855e+00 2.55492898e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809713e
+00 9.91131802e+00

1.05695461e+01 1.12421038e+01 1.19283007e
+01 1.26274342e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602384e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e
+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013584e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237678e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016596e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
4.93049015e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 10 -0.
008040573360104941

energy eigen vector for n= 10 [-2.98604996e+00 -
7.78588339e-01 -3.48957395e-01 -1.96526724e-
01
-1.11414663e-01 -1.04463943e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591399e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520854e+00 2.55492898e+00 2.94771408e
+00 3.36306143e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986531e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809713e
+00 9.91131801e+00
1.05695461e+01 1.12421038e+01 1.19283007e
+01 1.26274341e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917655e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602384e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e
+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013584e
+01 3.43487830e+01
3.50865590e+01 3.58139536e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e

```
+01 3.99208501e+01
 4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
 4.29338902e+01 4.34846404e+01 4.40168576e
+01 4.45300542e+01
 4.50237678e+01 4.54975637e+01 4.59510360e
+01 4.63838099e+01
 4.67955442e+01 4.71859338e+01 4.75547130e
+01 4.79016596e+01
 4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
 4.93049014e+01 4.95194243e+01 4.97124029e
+01 4.98843222e+01
 5.00358838e+01 5.01681152e+01 5.02826532e
+01 5.03829226e+01]
=====FOR I=2
=====
energy eigen value for n= 1 -0.
11111316867823891
energy eigen vector for n= 1 [-2.98604997e+00 -7.
78588339e-01 -3.48957395e-01 -1.96526724e-01
-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
 1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591400e-01
 9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
 2.18520855e+00 2.55492899e+00 2.94771408e
+00 3.36306144e+00
 3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
 5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
 8.02932050e+00 8.64054776e+00 9.26809714e
+00 9.91131802e+00
 1.05695461e+01 1.12421038e+01 1.19283007e
```

+01 1.26274342e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602385e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e
+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013585e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237679e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016597e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
4.93049015e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 2 -0.
06250195321028257
energy eigen vector for n= 2 [-2.98604997e+00 -7.

78588339e-01 -3.48957395e-01 -1.96526724e-01
-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-01
7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520855e+00 2.55492899e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809714e
+00 9.91131802e+00
1.05695461e+01 1.12421038e+01 1.19283007e
+01 1.26274342e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602385e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e
+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013585e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e

+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237679e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016597e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
4.93049015e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 3 -0.
040001485826807875
energy eigen vector for n= 3 [-2.98604997e+00 -7.
78588339e-01 -3.48957395e-01 -1.96526724e-01
-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520855e+00 2.55492899e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809714e
+00 9.91131802e+00
1.05695461e+01 1.12421038e+01 1.19283007e
+01 1.26274342e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e

+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602385e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e
+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013585e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237679e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016597e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
4.93049015e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 4 -0.
027778861798617244
energy eigen vector for n= 4 [-2.98604997e+00 -7.
78588339e-01 -3.48957395e-01 -1.96526724e-01
-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-

01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520855e+00 2.55492899e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809714e
+00 9.91131802e+00
1.05695461e+01 1.12421038e+01 1.19283007e
+01 1.26274342e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602385e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e
+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013585e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237679e+01 4.54975637e+01 4.59510360e

+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016597e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
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+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
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-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
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01 7.00591400e-01
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+00 1.83905468e+00
2.18520855e+00 2.55492899e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809714e
+00 9.91131802e+00
1.05695461e+01 1.12421038e+01 1.19283007e
+01 1.26274342e+01
1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602385e
+01 2.17561649e+01
2.25550630e+01 2.33561277e+01 2.41585521e

+01 2.49615287e+01
2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013585e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237679e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016597e+01
4.82266000e+01 4.85294146e+01 4.88100461e
+01 4.90685088e+01
4.93049015e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 6 -0.
01562559293454817
energy eigen vector for n= 6 [-2.98604997e+00 -7.
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-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
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01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520855e+00 2.55492899e+00 2.94771408e

+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809714e
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2.25550630e+01 2.33561277e+01 2.41585521e
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2.57642498e+01 2.65659085e+01 2.73656997e
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+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
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4.05561406e+01 4.11756772e+01 4.17788626e
+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237679e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016597e+01
4.82266000e+01 4.85294146e+01 4.88100461e

+01 4.90685088e+01
4.93049015e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 7 -0.
012346065637949225
energy eigen vector for n= 7 [-2.98604997e+00 -7.
78588339e-01 -3.48957395e-01 -1.96526724e-01
-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520855e+00 2.55492899e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809714e
+00 9.91131802e+00
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1.33387896e+01 1.40616415e+01 1.47952537e
+01 1.55388802e+01
1.62917656e+01 1.70531461e+01 1.78222503e
+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602385e
+01 2.17561649e+01
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+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e

+01 3.13086764e+01
3.20805472e+01 3.28450287e+01 3.36013585e
+01 3.43487830e+01
3.50865590e+01 3.58139537e+01 3.65302459e
+01 3.72347271e+01
3.79267018e+01 3.86054887e+01 3.92704216e
+01 3.99208501e+01
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+01 4.23651192e+01
4.29338902e+01 4.34846404e+01 4.40168577e
+01 4.45300542e+01
4.50237679e+01 4.54975637e+01 4.59510360e
+01 4.63838100e+01
4.67955443e+01 4.71859338e+01 4.75547130e
+01 4.79016597e+01
4.82266000e+01 4.85294146e+01 4.88100461e
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4.93049015e+01 4.95194244e+01 4.97124029e
+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 8 -0.
00999034571225721
energy eigen vector for n= 8 [-2.98604997e+00 -7.
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-1.11414663e-01 -1.04463944e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520855e+00 2.55492898e+00 2.94771408e
+00 3.36306144e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e

+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809714e
+00 9.91131802e+00
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2.25550630e+01 2.33561277e+01 2.41585521e
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2.57642498e+01 2.65659085e+01 2.73656997e
+01 2.81628205e+01
2.89564714e+01 2.97458571e+01 3.05301870e
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+01 3.72347271e+01
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+01 3.99208501e+01
4.05561406e+01 4.11756772e+01 4.17788626e
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4.29338902e+01 4.34846404e+01 4.40168577e
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4.67955443e+01 4.71859338e+01 4.75547130e
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+01 4.98843222e+01
5.00358838e+01 5.01681153e+01 5.02826532e

+01 5.03829226e+01]
energy eigen value for n= 9 -0.
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energy eigen vector for n= 9 [-2.98604996e+00 -7.
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-1.11414663e-01 -1.04463943e-02 0.00000000e
+00 0.00000000e+00
1.23433323e-01 2.87695862e-01 4.80479023e-
01 7.00591400e-01
9.47163314e-01 1.21949365e+00 1.51697527e
+00 1.83905468e+00
2.18520854e+00 2.55492898e+00 2.94771408e
+00 3.36306143e+00
3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014828e+00 6.29986532e+00 6.85836427e
+00 7.43505192e+00
8.02932050e+00 8.64054776e+00 9.26809713e
+00 9.91131801e+00
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+01 1.26274342e+01
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+01 1.85982993e+01
1.93805082e+01 2.01680864e+01 2.09602384e
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2.25550630e+01 2.33561277e+01 2.41585521e
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2.57642498e+01 2.65659085e+01 2.73656997e
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3.50865590e+01 3.58139537e+01 3.65302459e

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+01 3.99208501e+01
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4.67955443e+01 4.71859338e+01 4.75547130e
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4.82266000e+01 4.85294146e+01 4.88100461e
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4.93049014e+01 4.95194244e+01 4.97124029e
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5.00358838e+01 5.01681153e+01 5.02826532e
+01 5.03829226e+01]
energy eigen value for n= 10 -0.
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energy eigen vector for n= 10 [-2.98604996e+00 -
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-1.11414662e-01 -1.04463943e-02 0.00000000e
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2.18520854e+00 2.55492898e+00 2.94771408e
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3.80046368e+00 4.25940536e+00 4.73936067e
+00 5.23979189e+00
5.76014827e+00 6.29986531e+00 6.85836426e
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8.02932049e+00 8.64054775e+00 9.26809712e
+00 9.91131800e+00

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 1.62917655e+01 1.70531461e+01 1.78222503e
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 2.25550630e+01 2.33561276e+01 2.41585521e
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 3.20805472e+01 3.28450287e+01 3.36013584e
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+01 4.98843221e+01
 5.00358837e+01 5.01681152e+01 5.02826531e
+01 5.03829225e+01]
```

Process finished with exit code 0

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energy eigen value for n= 1 -0.9442719099991219

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energy eigen value for n= 3 -0.

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energy eigen value for n= 4 -0.

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energy eigen value for n= 5 -0.

03523240984866938

energy eigen value for n= 6 -0.

0033034399493594435

energy eigen value for n= 7 0.0

energy eigen value for n= 8 0.0

energy eigen value for n= 9 0.03903304401622698

energy eigen value for n= 10 0.

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=====FOR I=1

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energy eigen value for n= 1 -0.

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energy eigen vector for n= 1 [-2.98604992 -0.77858833 -0.34895739 -0.19652672 -0.11141466 -0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 2 -0.

11113514902287941

energy eigen vector for n= 2 [-2.98604995 -0.77858834 -0.34895739 -0.19652672 -0.11141466 -0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 3 -0.

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energy eigen vector for n= 3 [-2.98604996 -0.77858834 -0.34895739 -0.19652672 -0.11141466

-0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 4 -0.

040007101758064156

energy eigen vector for n= 4 [-2.98604996 -0.

77858834 -0.34895739 -0.19652672 -0.11141466

-0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 5 -0.

027782198101089756

energy eigen vector for n= 5 [-2.98604996 -0.

77858834 -0.3489574 -0.19652672 -0.11141466 -

0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 6 -0.

020411091854882685

energy eigen vector for n= 6 [-2.98604996 -0.

77858834 -0.3489574 -0.19652672 -0.11141466 -

0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 7 -0.

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0. 0. 0.12343332 0.28769586]

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energy eigen vector for n= 8 [-2.98604997 -0.

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0.01044639

0. 0. 0.12343332 0.28769586]

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energy eigen vector for n= 9 [-2.98604997 -0.

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0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 10 -0.

008040573360104941

energy eigen vector for n= 10 [-2.98604996 -0.

77858834 -0.3489574 -0.19652672 -0.11141466 -

0.01044639

0. 0. 0.12343332 0.28769586]

=====FOR I=2

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energy eigen vector for n= 1 [-2.98604997 -0.

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0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 2 -0.

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energy eigen vector for n= 2 [-2.98604997 -0.

77858834 -0.3489574 -0.19652672 -0.11141466 -

0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 3 -0.

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energy eigen vector for n= 3 [-2.98604997 -0.

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0.01044639

0. 0. 0.12343332 0.28769586]

energy eigen value for n= 4 -0.

027778861798617244

energy eigen vector for n= 4 [-2.98604997 -0.

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0.01044639

0. 0. 0.12343332 0.28769586]

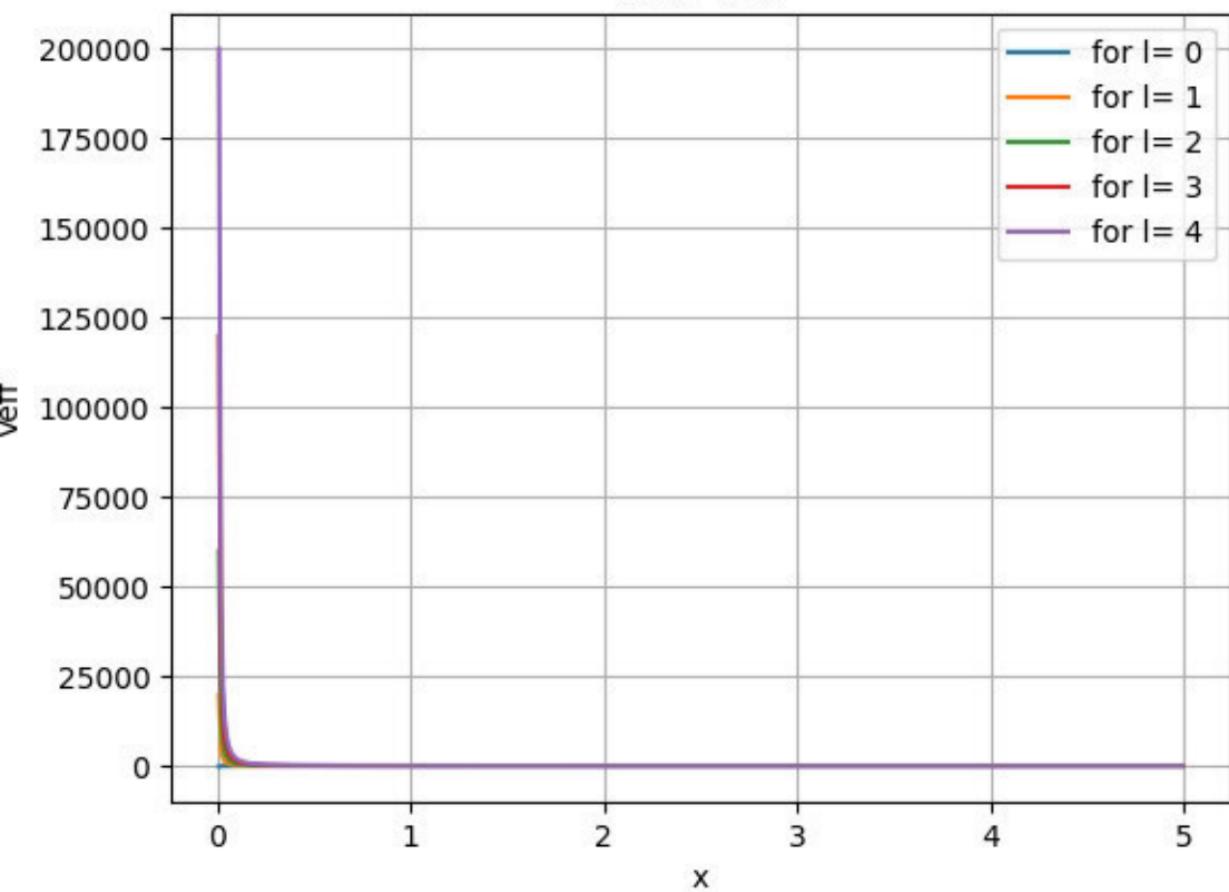
energy eigen value for n= 5 -0.

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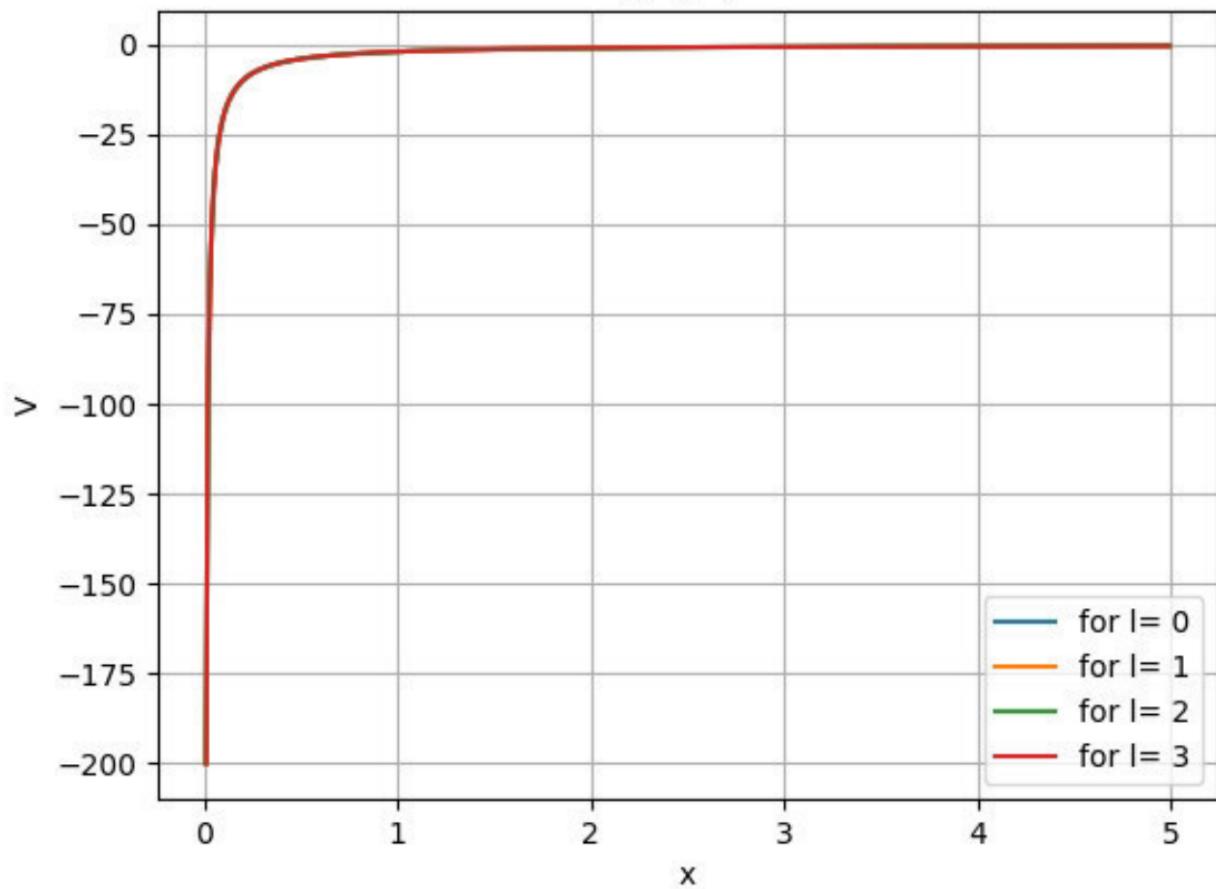
energy eigen vector for n= 5 [-2.98604997 -0.
77858834 -0.3489574 -0.19652672 -0.11141466 -
0.01044639
0. 0. 0.12343332 0.28769586]
energy eigen value for n= 6 -0.
01562559293454817
energy eigen vector for n= 6 [-2.98604997 -0.
77858834 -0.3489574 -0.19652672 -0.11141466 -
0.01044639
0. 0. 0.12343332 0.28769586]
energy eigen value for n= 7 -0.
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energy eigen vector for n= 7 [-2.98604997 -0.
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0.01044639
0. 0. 0.12343332 0.28769586]
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energy eigen vector for n= 8 [-2.98604997 -0.
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0.01044639
0. 0. 0.12343332 0.28769586]
energy eigen value for n= 9 -0.
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energy eigen vector for n= 9 [-2.98604996 -0.
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0.01044639
0. 0. 0.12343332 0.28769586]
energy eigen value for n= 10 -0.
005922734307938285
energy eigen vector for n= 10 [-2.98604996 -0.
77858834 -0.34895739 -0.19652672 -0.11141466
-0.01044639
0. 0. 0.12343332 0.28769586]

Process finished with exit code 0

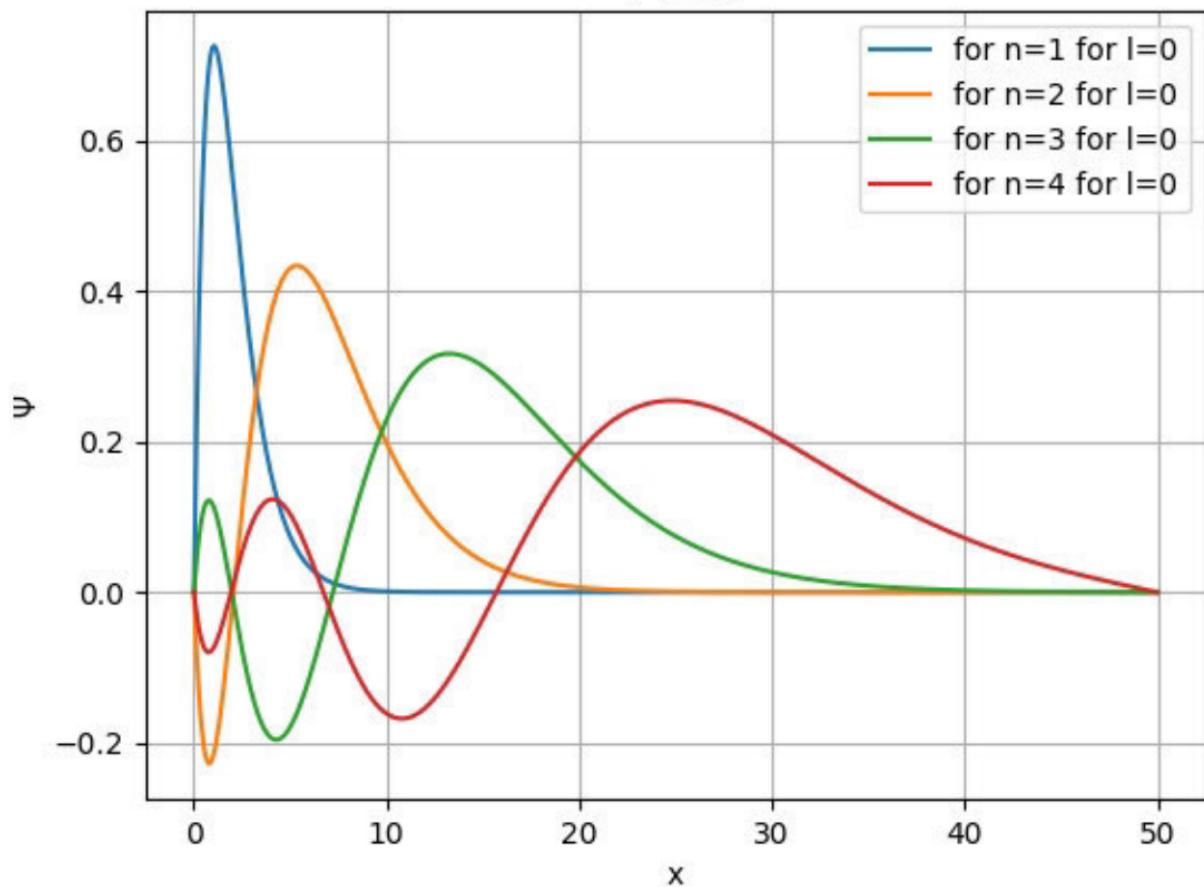
x VS Veff



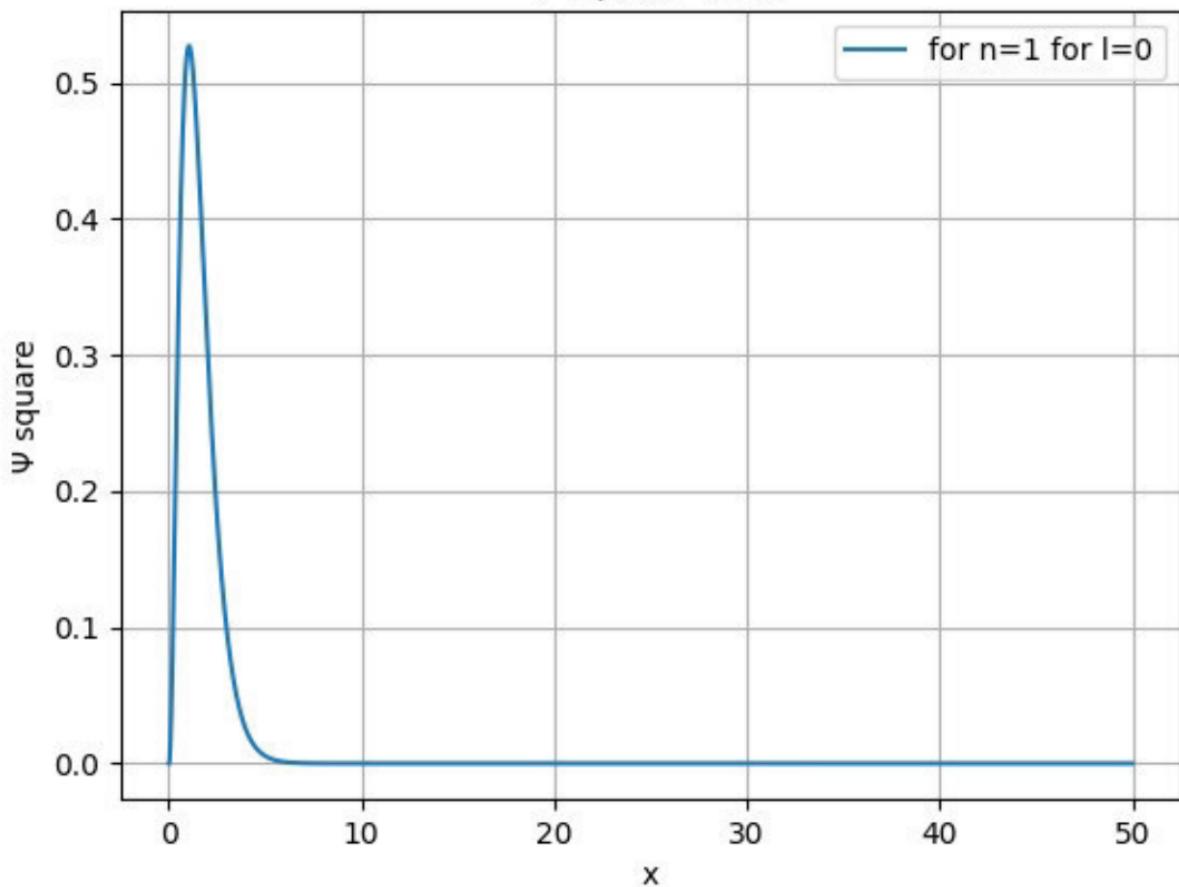
x VS V



Ψ VS x



Ψ square VS x



Ψ square VS x

