RELATIVISTIC AND NON-RELATIVISTIC

Before moving to the practical let's see the basic terms and definition for proper understanding:

Relativistic Bosons:

Relativistic bosons are particles that obey Bose-Einstein statistics and have energies comparable to their rest mass energy. The distribution function for bosons is given by the Bose-Einstein distribution:

$$n(E) = \frac{1}{\exp\left(\frac{E-\mu}{k_B T}\right) - 1}$$

where:
- E is the energy of the particles.
- μ is the chemical potential.
- k_B is the Boltzmann constant.
- T is the temperature.

The density of states $g(E)$ in three dimensions for relativistic particles (considering spin s and volume V) is:

$$g(E) = \frac{2s \cdot 4\pi V}{h^3 c^3} E^2$$

The particle distribution with respect to energy is given by:

$$\frac{dN}{dE} = g(E) \cdot n(E)$$

Nonrelativistic Bosons:

Non-relativistic bosons are particles whose kinetic energy is much less than their rest mass energy. The distribution function for bosons is still the Bose-Einstein distribution, but the density of states $g(E)$ for non-relativistic particles is different:

$$g(E) = \frac{(2s+1) \cdot 2\pi V (2m)^{3/2}}{h^3} E^{1/2}$$

Here, m is the mass of the particles. The particle distribution with respect to energy remains:

$$\frac{dN}{dE} = g(E) \cdot n(E)$$

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Relativistic Fermions:

Relativistic fermions are particles that obey Fermi-Dirac statistics and have energies comparable to their rest mass energy. The distribution function for fermions is given by the Fermi-Dirac distribution:

$$n(E) = \frac{1}{\exp\left(\frac{E-\mu}{k_B T}\right) + 1}$$

The density of states $g(E)$ in three dimensions for relativistic particles is:

$$g(E) = \frac{2s \cdot 4\pi V}{h^3 c^3} E^2$$

The particle distribution with respect to energy is:

$$\frac{dN}{dE} = g(E) \cdot n(E)$$

Non-Relativistic Fermions:

Non-relativistic fermions are particles whose kinetic energy is much less than their rest mass energy. The Fermi-Dirac distribution still applies. The density of states $g(E)$ for non-relativistic particles is:

$$g(E) = \frac{(2s+1) \cdot 2\pi V (2m)^{3/2}}{h^3} E^{1/2}$$

The particle distribution with respect to energy is:

$$\frac{dN}{dE} = g(E) \cdot n(E)$$

EXPERIMENT 8

AIM: Plot the distribution of particles w.r.t. energy (dN/dE versus E) in 3 Dimensions for relativistic bosons both at high and low temperature.

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CODE:

```
import numpy as np
import matplotlib.pyplot as plt

# Initializing the constants
e = 1.6e-19 ;Kb = 1.38e-23 ;h = 6.626e-34 ;s = 1 ;u = -1 ;V = 1 ;c = 3e8

E = np.arange(0, 0.501, 0.001) # Energy range in MeV
T = [10**8, 10**9] # Temperatures in K

# Defining the g(E)
```

```
Cr = (2 * s * 4 * np.pi * V) / ((h**3) * (c**3))
g = Cr * E**2

# Prepare the figure for plotting
plt.figure(figsize=(15, 10))

# Loop over temperatures to compute and plot n(E) and f(E) for each temperature
for j, temp in enumerate(T):
    b = 1 / (Kb * temp)

    # Calculating n(E), and f(E) for the given temperature
    n = 1 / (np.exp((E - u) * 10**6 * e * b) - 1)
    f = g * n

    plt.subplot(2, 3, j * 3 + 1)  # Plot g(E)
    plt.plot(E, g, linewidth=4)
    plt.ylabel('g(E)', fontsize=12)
    plt.xlabel('Energy (MeV)', fontsize=12)
    plt.title('Density of States', fontsize=14)

    plt.subplot(2, 3, j * 3 + 2)  # Plot n(E)
    plt.plot(E, n, linewidth=4, label=f'{temp}K')
    plt.ylabel('n(E)', fontsize=12)
    plt.xlabel('Energy (MeV)', fontsize=12)
    plt.title(f'Relativistic Bosons (s={s}, u={u} MeV)', fontsize=14)
    plt.legend()

    plt.subplot(2, 3, j * 3 + 3)  # Plot dN/dE
    plt.plot(E, f, linewidth=4, label=f'{temp}K')
    plt.ylabel('dN/dE', fontsize=12)
    plt.xlabel('Energy (MeV)', fontsize=12)
    plt.title('Occupation Number Distribution', fontsize=14)
    plt.legend()
plt.tight_layout()
plt.show()
```

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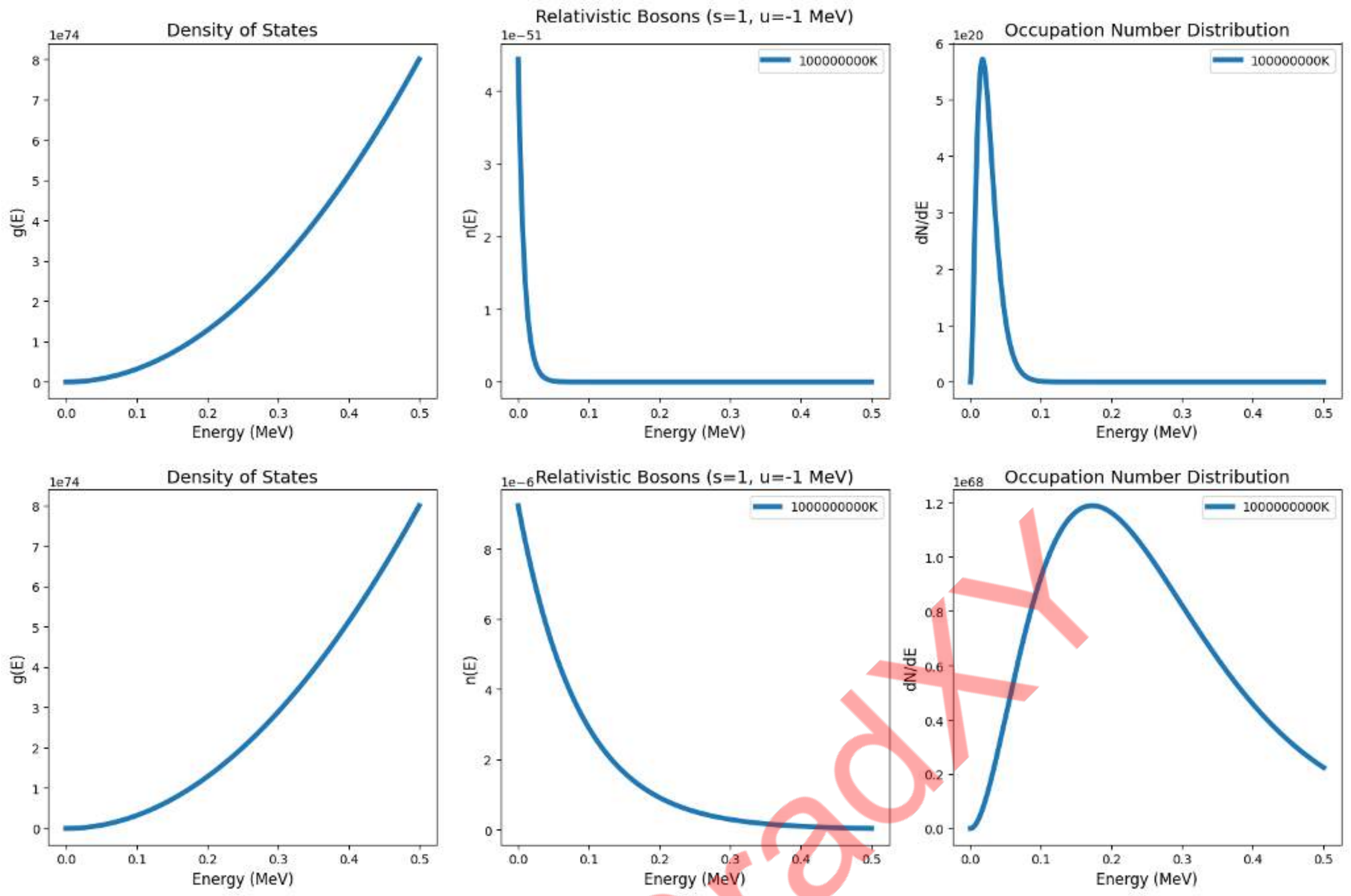
OUTPUT:



EXPERIMENT 9

AIM: Plot the distribution of particles w.r.t. energy (dN/dE versus E) in 3 Dimensions for non-relativistic bosons both at high and low temperature.

CODE:

```
import numpy as np
import matplotlib.pyplot as plt

# Initializing the constants
e = 1.6e-19 ;Kb = 1.38e-23 ;h = 6.626e-34 ;s = 1 ;u = -1 ; V = 1; m = 4 * 1.66e-27
E = np.arange(0, 0.501, 0.001) # Energy range in eV
T = [100, 1000] # Temperatures in K

# Defining g(E)
Cn = ((2 * s + 1) * (2 * np.pi * V) * (2 * m)**1.5) / (h**3)
g = Cn * E**2

# Plotting the graphs
plt.figure(figsize=(15, 10))

# Loop over temperatures to compute and plot n(E) and f(E) for each temperature
```

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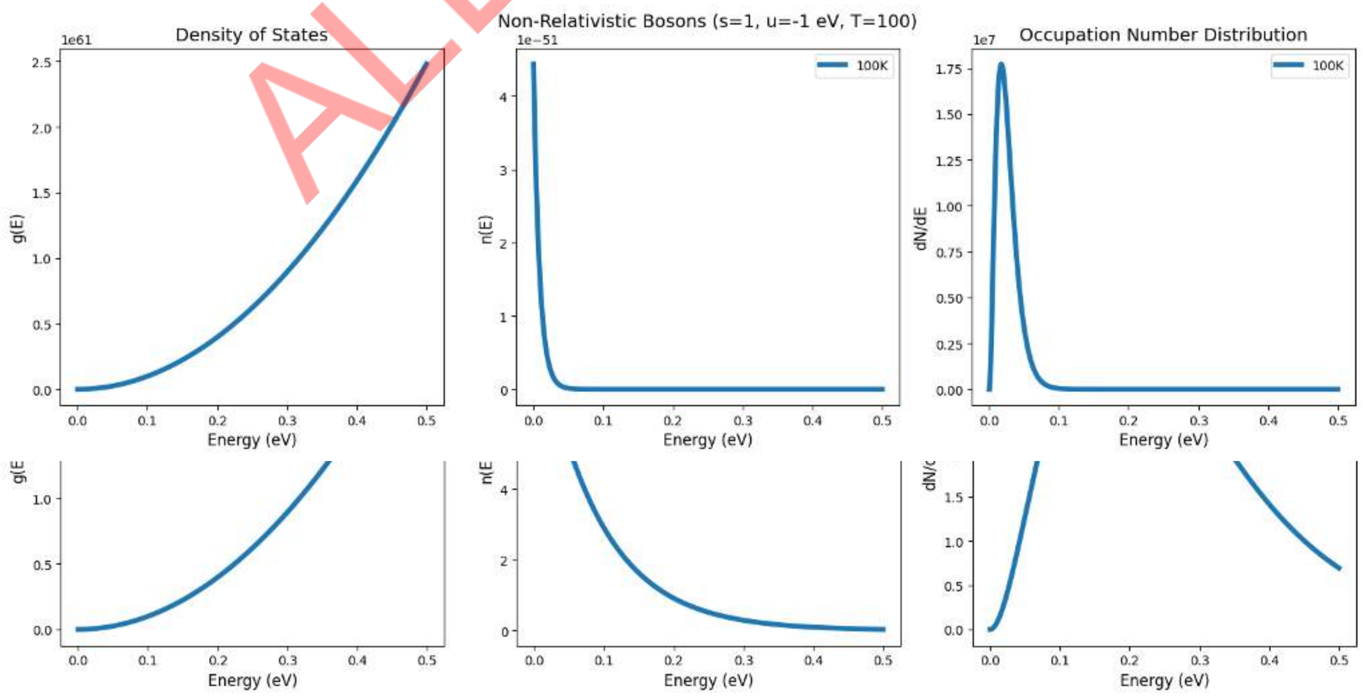
```
for j, temp in enumerate(T):
    b = 1 / (Kb * temp)

    # Calculating n(E) and f(E) for the given temperature
    n = 1 / (np.exp((E - u) * e * b) - 1)
    f = g * n

    plt.subplot(2, 3, j * 3 + 1) # Plot g(E)
    plt.plot(E, g, linewidth=4)
    plt.ylabel('g(E)', fontsize=12)
    plt.xlabel('Energy (eV)', fontsize=12)
    plt.title('Density of States', fontsize=14)

    plt.subplot(2, 3, j * 3 + 2) # Plot n(E)
    plt.plot(E, n, linewidth=4, label=f'{temp}K')
    plt.ylabel('n(E)', fontsize=12)
    plt.xlabel('Energy (eV)', fontsize=12)
    plt.title(f'Non-Relativistic Bosons (s={s}, u={u} eV, T={temp})', fontsize=14)
    plt.legend()

    plt.subplot(2, 3, j * 3 + 3)  # Plot dN/dE
    plt.plot(E, f, linewidth=4, label=f'{temp}K')
    plt.ylabel('dN/dE', fontsize=12)
    plt.xlabel('Energy (eV)', fontsize=12)
    plt.title('Occupation Number Distribution', fontsize=14)
    plt.legend()
plt.tight_layout()
plt.show()
```

OUTPUT:



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EXPERIMENT 10

AIM: Plot the distribution of particles w.r.t. energy (dN/dE versus E) in 3 Dimensions for relativistic fermions both at high and low temperature.

CODE:

```
import numpy as np
import matplotlib.pyplot as plt

# Initializing the constants
e = 1.6e-19; Kb = 1.38e-23; h = 6.626e-34; s = 0.5; u = 1; V = 1; c = 3e8

E = np.arange(0, 2.001, 0.001) # Energy range in MeV
T = [10**8, 10**9] # Temperatures in K

# Defining g(E)
Cr = (2 * s * 4 * np.pi * V) / ((h**3) * (c**3))
g = Cr * (E**2)

# Calculate n(E), and f(E) for each temperature
n = []
f = []

for temp in T:
    b = 1 / (Kb * temp)
    n_temp = 1 / (np.exp((E - u) * 10**6 * e * b) + 1)
    f_temp = g * n_temp
    n.append(n_temp)
    f.append(f_temp)

# Convert lists to numpy arrays
n = np.array(n)
f = np.array(f)

# Plotting the graphs
plt.figure(figsize=(15, 5))

plt.subplot(1, 3, 1) # Plot g(E)
plt.plot(E, g, linewidth=4)
plt.ylabel('g(E)', fontsize=12)
plt.xlabel('Energy (MeV)', fontsize=12)
plt.title('Density of States g(E)', fontsize=14)
plt.legend()
```

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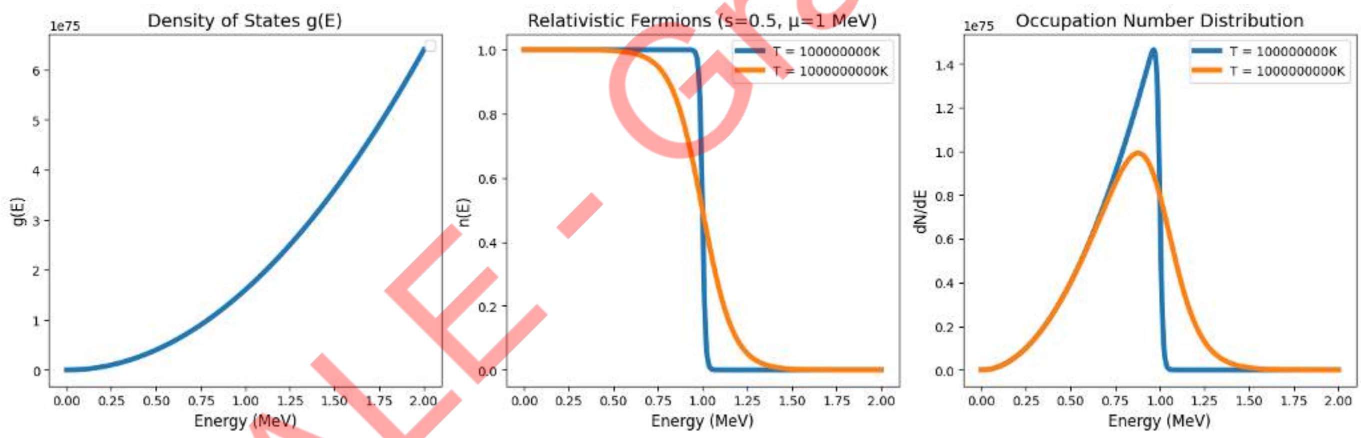
```python
plt.subplot(1, 3, 2) # Plot n(E)
for j, temp in enumerate(T):
    plt.plot(E, n[j], linewidth=4, label=f'T = {temp}K')
plt.ylabel('n(E)', fontsize=12)
plt.xlabel('Energy (MeV)', fontsize=12)
plt.title(f'Relativistic Fermions (s={s}, μ={u} MeV)', fontsize=14)
plt.legend()

plt.subplot(1, 3, 3) # Plot dN/dE
for j, temp in enumerate(T):
    plt.plot(E, f[j], linewidth=4, label=f'T = {temp}K')
plt.ylabel('dN/dE', fontsize=12)
plt.xlabel('Energy (MeV)', fontsize=12)
plt.title('Occupation Number Distribution', fontsize=14)
plt.legend()

plt.tight_layout()
plt.show()
```

OUTPUT:



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EXPERIMENT 11

AIM: Plot the distribution of particles w.r.t. energy (dN/dE versus E) in 3 Dimensions for non-relativistic fermions both at high and low temperature.

CODE:

```python
import numpy as np
import matplotlib.pyplot as plt

# Initializing the constants
e = 1.6e-19; Kb = 1.38e-23; h = 6.626e-34; s = 0.5; u = 1; V = 1; m = 9.1e-31
```

```
E = np.arange(0, 2.001, 0.001) # Energy range in eV
T = [100, 1000] # Temperatures in K

# Defining g(E)
Cn = (2 * s + 1) * (2 * np.pi * V * (2 * m)**1.5) / (h**3)
g = Cn * (E**0.5)

# Initializing arrays for n(E) and f(E)
n = np.zeros((len(T), len(E)))
f = np.zeros((len(T), len(E)))

# Calculating n(E) and f(E) for each temperature
for j in range(len(T)):
    b = 1 / (Kb * T[j])
    for i in range(len(E)):
        n[j, i] = 1 / (np.exp((E[i] - u) * e * b) + 1)
        f[j, i] = g[i] * n[j, i]

# Plotting the graphs
plt.figure(figsize=(15, 5))

plt.subplot(1, 3, 1) # Plot g(E)
plt.plot(E, g, linewidth=4)
plt.ylabel('g(E)', fontsize=12)
plt.xlabel('Energy (eV)', fontsize=12)
plt.title('Density of States g(E)', fontsize=14)

plt.subplot(1, 3, 2) # Plot n(E)
for j in range(len(T)):
    plt.plot(E, n[j], label=f'{T[j]}K', linewidth=4)
plt.ylabel('n(E)', fontsize=12)
plt.xlabel('Energy (eV)', fontsize=12)
plt.title(f'Fermi-Dirac Distribution (s={s}, μ={u}eV)', fontsize=14)
plt.legend()

plt.subplot(1, 3, 3) # Plot dN/dE
for j in range(len(T)):
    plt.plot(E, f[j], label=f'{T[j]}K', linewidth=4)
plt.ylabel('dN/dE', fontsize=12)
plt.xlabel('Energy (eV)', fontsize=12)
plt.title('Occupation Number Distribution', fontsize=14)
plt.legend()

plt.tight_layout()
plt.show()
```

OUTPUT:

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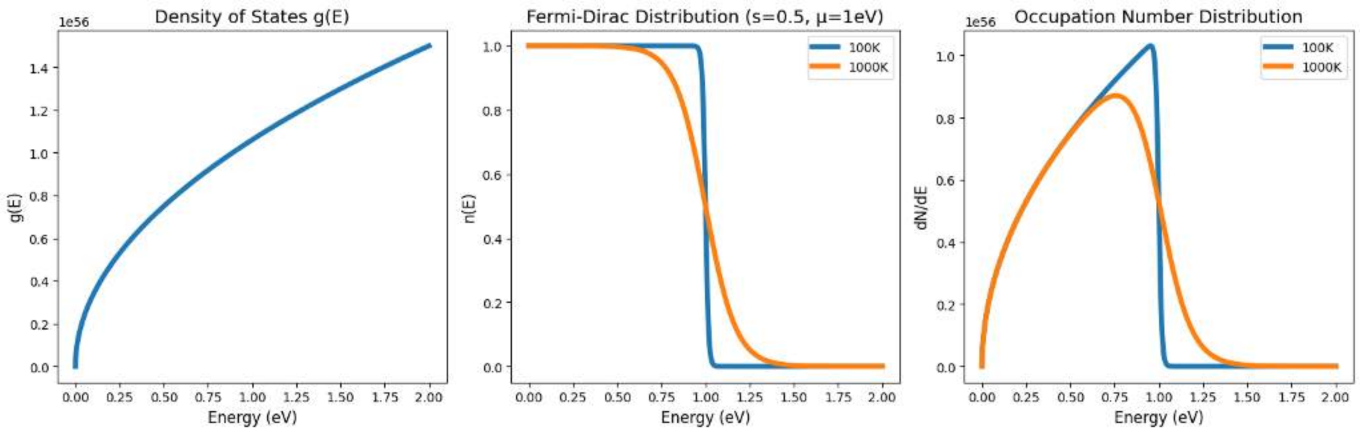

Density of States g(E)
1e56
g(E)
Energy (eV)
Fermi-Dirac Distribution (s=0.5, μ=1eV)
n(E)
100K
1000K
Energy (eV)
Occupation Number Distribution
1e56
dN/dE
100K
1000K
Energy (eV)

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