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ME564 – Autumn 2025

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HOMEWORK - 01

Excercise 1-1: Compute the derivate of following:

(a) $f(x) = \sin(x^2)$

⇒ using chain rule to solve this composite function

As we know,

$$\frac{d}{dx}[f(g(x))] = f'(g(x)) \cdot g'(x) \quad \text{—— I}$$

So, $f(a) = \sin(a)$

& $g(x) = x^2$

∴ $f'(a) = \cos(a)$ —— 1

& $g(x) = x^2 \Rightarrow g'(x) = 2x$ —— 2

Using 1 & 2 in I, we get

$$f'(x) = f'(g(x)) \cdot g'(x)$$
$$= \cos(x^2) \cdot 2x$$

∴ ~~$f'(x) = 2x\cos(x)^2$~~ $\boxed{f'(x) = 2x\cos(x^2)}$

(b) $f(x) = x^x$

⇒ Let $y = x^x$ —— 1

By taking natural logarithm on both sides,

$$\ln(y) = \ln(x^x)$$
$$\therefore \ln(y) = x\ln(x)$$

Differentiate on both sides,

$$\frac{d}{dx}[\ln(y)] = \frac{d}{dx}[x\ln(x)]$$

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using chain rule of left side & product rule on right side, we get:

$$\frac{1}{y}\frac{dy}{dx} = \ln(x) + 1$$

→ Solving for $\frac{dy}{dx}$; multiply both sides by y.

$$\therefore \frac{dy}{dx} = y(\ln(x) + 1)$$

As we know from ① that $y = x^x$

$$\therefore \frac{dy}{dx} = x^x(\ln(x) + 1)$$

$$\therefore \boxed{f'(x) = x^x(\ln(x) + 1)}$$

(c) $f(x) = e^{\cos(3x)}\cos(x)$

⇒ As per product rule:

$$(x \cdot y)' = x'y + y'x \quad \text{—— ①}$$

so, let $x = e^{\cos(3x)}$

& $y = \cos(x)$

→ Differentiate each part:

$$x' = e^{\cos(3x)} \cdot (-3\sin(3x)) \qquad \because \frac{d[e^{g(x)}]}{dx} = e^{g(x)} \cdot g'(x)$$

$$x' = -3e^{\cos(3x)}\sin(3x) \quad \text{—— ②}$$

& $y' = -\sin(x)$ —— ③

Now, from ①, ② & ③ we get,

~~f'(x) ⟶ x~~ $f'(x) = [-3\sin(3x)e^{\cos(3x)}] \cdot [\frac{\cos(x)}{\cancel{\sin(x)}}]$
$+ e^{\cos(3x)}(-\sin(x))$

$$\therefore \boxed{f'(x) = e^{\cos(3x)}\left\{[-3\sin(3x)\cdot\cos(x)] - [\sin(x)]\right\}}$$

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(d) $f(x,y) = \sin(x^2 - y^2)$ w.r.t t, assuming that $x(t)$ & $y(t)$ vary with time.

⇒ Lets assume

$x = x(t)$ & $y = y(t)$ are function of time

Now, by chain rule: (multivariable)

$$\frac{df}{dt} = \frac{\partial f}{\partial x}\frac{dx}{dt} + \frac{\partial f}{\partial y}\frac{dy}{dt} \longrightarrow (1)$$

So, partial derivites are as follows:

$$\frac{\partial f}{\partial x} = \cos(x^2 - y^2) \cdot 2x$$

$$\frac{\partial f}{\partial y} = -2y \cdot \cos(x^2 - y^2)$$

→ by chain rule

Using above in eq^n (1), we get:

$$\frac{df}{dt} = \left[2x\cos(x^2-y^2)\right]\frac{dx}{dt} + \left[-2y\cos(x^2-y^2)\right]\frac{dy}{dt}$$

$$\therefore \boxed{\frac{df}{dt} = 2\cos(x^2-y^2)\left[x\frac{dx}{dt} - y\frac{dy}{dt}\right]}$$

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Excercise 1-2: A given mass x of a radioactive element obeys the following differential equation: $\dot{x} = \lambda x$

where $\lambda \Rightarrow$ constant of rate of decay

ⓐ Solution for $x(t)$ to the differential equation

$\Rightarrow$ Rearranging eq^n & integrating on both sides:

$$\frac{dx}{x} = \lambda\, dt$$

$$\therefore \int \frac{1}{x} dx = \int \lambda\, dt$$

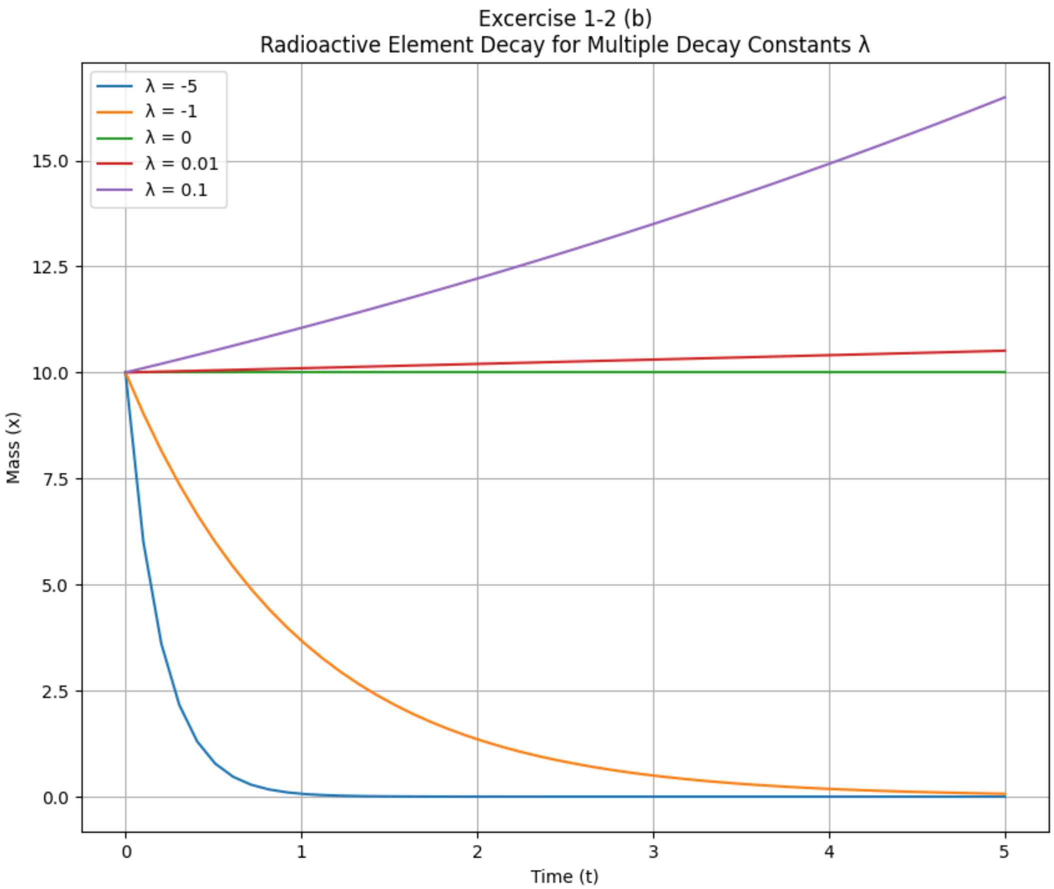
$$\therefore \ln|x| = \lambda t + C$$

Exponentiating on both sides:

$$x(t) = e^{\lambda t + C} = e^{C} e^{\lambda t}$$

Here, $x_0 = e^C$ as the initial mass at $t=0$

$$\therefore \boxed{x(t) = x_0 e^{\lambda t}}$$




```python
'''
Filename: e_2_b.py
Date Created: 10/09/2025
Created by: Archit Jain
Email: architj@uw.edu
Student No: 2426587
Description: Excercise 1-2: (b)
A given mass x of a radioactive element obeys the following differential equation
in time:
 ẋ = λx,
where λ is a constant describing the rate of decay.
Plot the solution for an initial condition x(0) = 10
From time t = 0 to t = 5 for λ = -5, -1, 0, 0.01, 0.1.
Please plot these all on the same figure. Include a legend.
'''


# Importing libraries
import numpy as np                    # for arrays data storage
```

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```
import matplotlib.pyplot as plt     # for plotting graphs

# Define the function to compute x(t)
def compute_x_t(x_0, t, lambda_const):
    '''
    A function that loops and plot for each lambda_const with graph dim 10x8
    '''
    plt.figure(figsize=(10, 8))
    # looping for lambda in given list
    for λ in lambda_const:
        # x(t) = x(0) * e^(λ*t)
        x_t = x_0 * np.exp(λ * t)
        plt.plot(t, x_t, label=f'λ = {λ}')
    return plt

# Given: Initial condition
x_0 = 10

# Setting a time array from 0->5 with 50 points from t=0 to t=5
t = np.linspace(0, 5, 50)

# Setting list for decay constants λ from the given list:
lambda_const = [-5, -1, 0, 0.01, 0.1]

# Compute x(t) and plot them w.r.t t for differnet lambda
plt = compute_x_t(x_0, t, lambda_const)

# Adding legends to graph plotted
plt.xlabel('Time (t)')
plt.ylabel('Mass (x)')
plt.title('Excercise 1-2 (b)\nRadioactive Element Decay for Multiple Decay
Constants λ')
plt.legend()
# Show grid to the plot
plt.grid(True)
# Display the graph plotted
plt.show()
```

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(c) The half-life T is defined as the time it takes for the material to be reduced to half of it's mass through radioactive decay. The half-life of Uranium-238 is 4.468 billion years. What is corresponding value of λ?

$\Rightarrow$ T = half-life time
(time taken to be reduced to half its initial mass.)

$\therefore$ eqⁿ with decay formula:

$$x(t) = x_0 e^{\lambda t}$$

becomes,

$$\frac{1}{2} x_0 = x_0 e^{\lambda T}$$

$$\therefore \quad \frac{1}{2} = e^{\lambda T}$$

Taking log on both sides:

$$\ln\left(\frac{1}{2}\right) = \lambda T$$

$$-\ln(2) = \lambda T$$

Solving for value λ;

$$\cancel{\lambda = \frac{-T}{\ln(2)}} \quad \lambda = \frac{-\ln(2)}{T}$$

As, $T_{uranium\,238} = 4.468 \times 10^9$ years $\longrightarrow$ (given)

$$\therefore \quad \boxed{\lambda = \frac{-\ln(2)}{4.468 \times 10^9 \text{ years}} \approx -1.551 \times 10^{-10} \text{ years}^{-1}}$$

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(d) If you start with 50 kg of uranium-238, how long until you only have 5 kg left? If you have 10 kg of uranium-238, how long ago was it 50 kg?

⇒ How long until 5 kg is left from 50 kg?

Here, initial mass $x_0 = 50$ kg

final mass $x(t) = 5$ kg

As, $x(t) = x_0 e^{\lambda t}$

$\lambda = -1.551 \times 10^{-10}$ → from previous solution (c)

$\therefore \quad 5 = 50 e^{(-1.551 \times 10^{-1})t} \Rightarrow 0.1 = e^{(-1.551 \times 10^{-10})t}$

Taking log on both sides,

$$\ln(0.1) = (-1.551 \times 10^{-10})t$$

$$\therefore \quad t \approx \frac{-2.3026}{-1.551 \times 10^{-10}} \approx 1.485 \times 10^{10}$$

$$\therefore \quad \boxed{t \approx 1.485 \times 10^{10} \text{ years}}$$

⇒ How long ago was it 50 kg, if it is 10 kg now?

Here, $x_0 = 50$ kg → initial mass

$x(t) = 10$ kg → final mass (now)

As, $x(t) = x_0 e^{\lambda t}$

$$\therefore \quad 10 = 50 e^{(-1.551 \times 10^{-10})t}$$

$$0.2 = e^{(-1.551 \times 10^{-10})t}$$

Taking log on both sides:

$$\ln(0.2) = (-1.551 \times 10^{-10})t$$

$$\therefore \quad t \approx = \frac{-1.6094}{-1.551 \times 10^{-10}} \approx 1.038 \times 10^{10}$$

$\therefore$ Approx. $\boxed{\text{10.38 billion year ago}}$ there was 50 kg of Uranium-238

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Exercise 1-3: compute taylor series expansion by hand for f(x)

ⓐ $f(x) = \sin(x)/x$

$\Rightarrow$ As per Maclaren series at basepoint $a = 0$

$$f(x) = f(a) + \frac{df}{dx}(x-a) + \frac{d^2f}{dx^2}\frac{(x-a)^2}{2!} + \cdots$$

---- evaluated at $a = 0$]

$$\therefore f(x) = f(0) + f'(0)(x-0) + f''(0)\cdot\frac{(x-0)^2}{2!} + \cdots$$

~~As fx = si~~ for $\sin(x)$]

$$f(x) = \sin(0) + \cos(0)(x) + \left(-\sin(0)\times\frac{x^2}{2!}\right) + \left(-\cos(0)\cdot\frac{x^3}{3!}\right)$$

$$= 0 + 1\cdot x + \left(-0\times\frac{x^2}{2!}\right) + \left(-1\cdot\frac{x^3}{3!}\right) + \cdots$$

$$\therefore f(x) \Rightarrow \sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} + \cdots = \sum_{n=0}^{\infty}(-1)^n\frac{x^{2n+1}}{(2n+1)!}$$

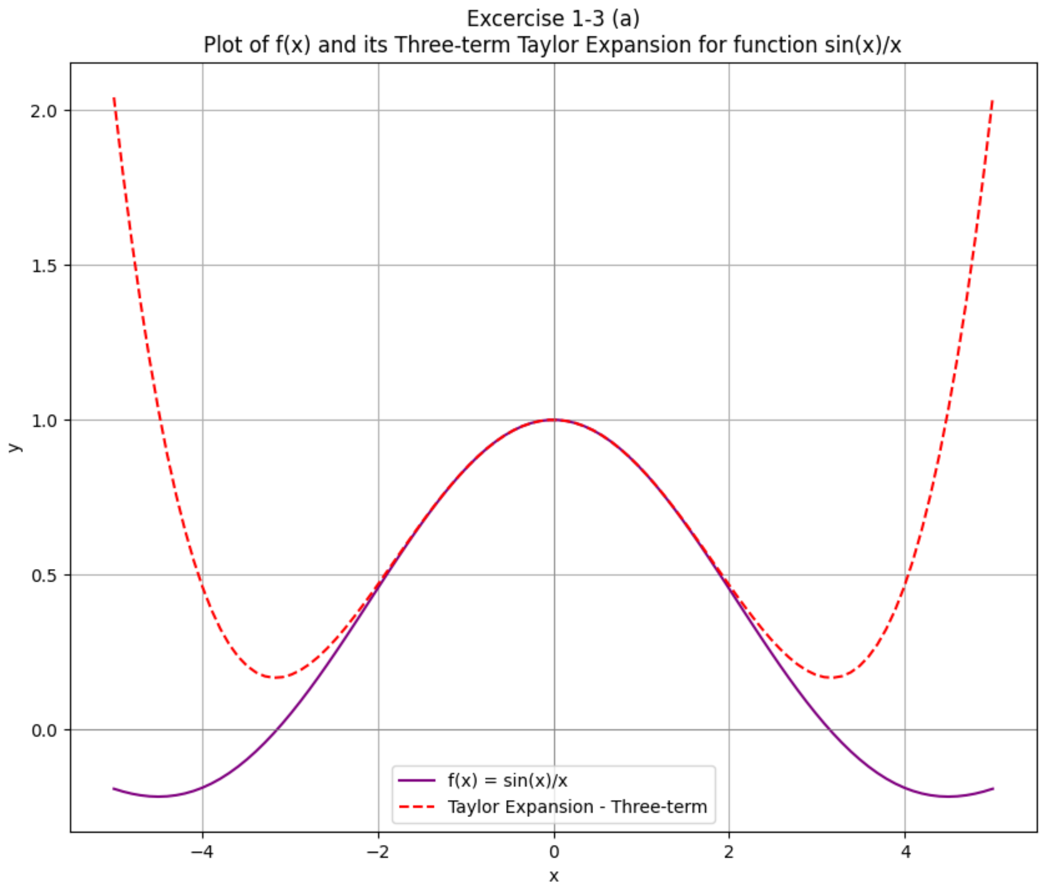
$\therefore$ Taylor series for $\frac{\sin(x)}{x}$ is by dividing above by x

$$\therefore \frac{\sin(x)}{x} = \frac{1}{x}\left(x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots\right)$$

$$\boxed{\frac{\sin(x)}{x} = 1 - \frac{x^2}{3!} + \frac{x^4}{5!} - \frac{x^6}{7!} + \cdots}$$

First three non-zero terms of above series are:

$$P_3(x) = 1 - \frac{x^3}{6} + \frac{x^4}{120}$$




```python
'''
Filename: e_3_a.py
Date Created: 10/09/2025
Created by: Archit Jain
Email: architj@uw.edu
Student No: 2426587
Description: Excercise 1-3: (a)
Compute the Taylor series expansion by hand for f (x).
For each function, plot f (x) = sin(x)/x
and the three-term expansion (i.e., the first three nonzero terms) from x = -5 to
x = 5.
'''

# Importing libraries
import math                         # for math operations
import numpy as np                  # for arrays data storage
import matplotlib.pyplot as plt     # for plotting graphs
```

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```
# Define the function f(x)
def compute_f(x):
    '''
    A function that computes f(x) = sin(x)/x for different values of x
    and also handles values where x=0 to be used as 1 to avoid singularity
errors.
    '''
    return np.where(x == 0, 1, np.sin(x) / x)

# Define the three-term Taylor expansion
def compute_taylor_expansion(x):
    '''
    A function that returns 3-term taylor expansion of f(x) = sin(x)/x
    # P_3(x) = [1 - (x^2/3!) + (x^4/5!)]
    '''
    first_term = 1
    second_term = (x**2) / math.factorial(3)
    third_term = (x**4) / math.factorial(5)
    return first_term - second_term + third_term

# Setting a x array from -5->5 with 100 points from x=-5 to x=5
x_val = np.linspace(-5, 5, 100)

# Calculate y values for f(x)
f_x = compute_f(x_val)
# Calculate the Three-term Taylor expansion
y_val = compute_taylor_expansion(x_val)

# Setting graph dimensions 10x8
plt.figure(figsize=(10, 8))
# Plotting points on graph
plt.plot(x_val, f_x, label='f(x) = sin(x)/x', color='purple')
plt.plot(x_val, y_val, label='Taylor Expansion - Three-term', color='red',
linestyle='--')
# Adding title and legends to graph plotted
plt.xlabel('x')
plt.ylabel('y')
plt.title('Excercise 1-3 (a)\nPlot of f(x) and its Three-term Taylor Expansion
for function sin(x)/x')
plt.legend()
# Show grid to the plot
plt.grid(True)
# Highlighting the origin lines
plt.axvline(0, color='gray', linestyle='-', linewidth=0.5)
plt.axhline(0, color='gray', linestyle='-', linewidth=0.5)
```

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```
# Display the graph plotted
plt.show()
```

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(b) $f(x) = (\cos(x) - 1)/x$

$\Rightarrow$ The macleron series for $\cos(x)$ at $a=0$ $\Downarrow$

$$\cos(x) = \sum_{n=0}^{\infty} \frac{(-1)^n x^{2n}}{2n!} = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \cdots$$

So, to solve for $(\cos(x) - 1)/x$, $\Downarrow$

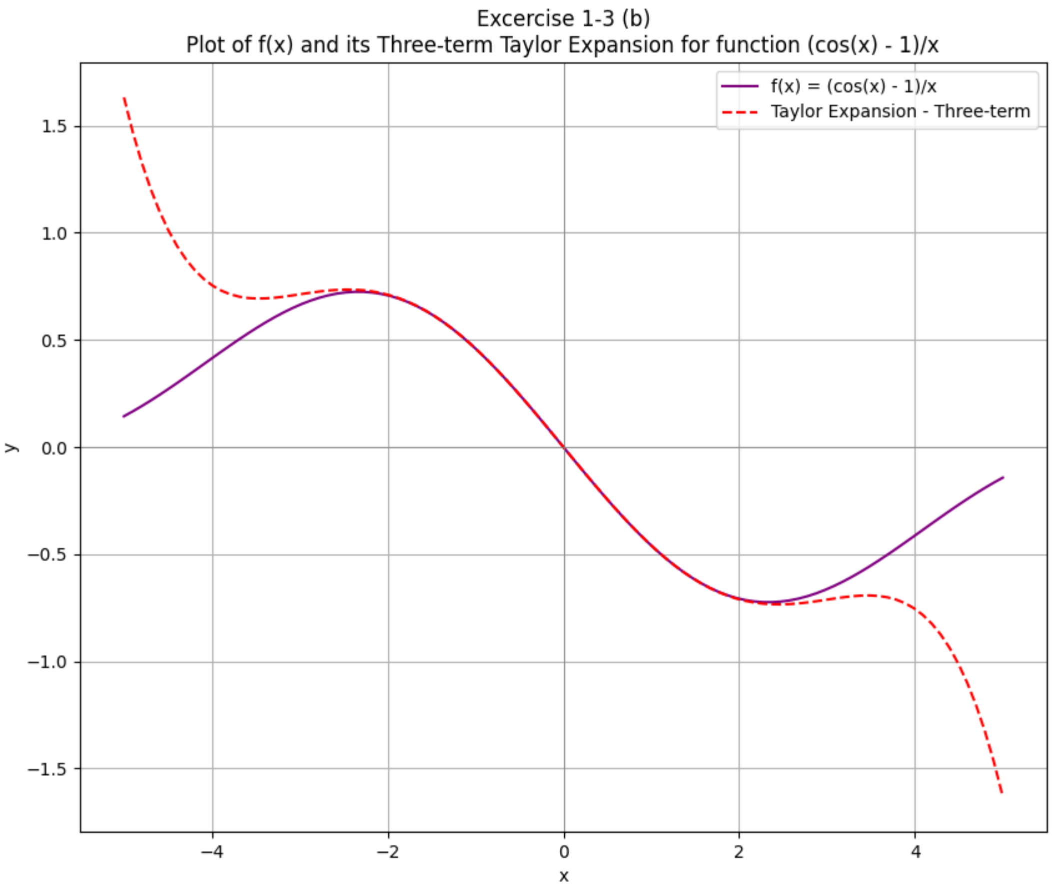
$$\frac{(\cos(x)-1)}{x} = \frac{\left(1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \cdots\right) - 1}{x}$$

$$\frac{\cos(x)-1}{x} = \frac{1}{x}\left(-\frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \cdots\right)$$

$$\boxed{\frac{\cos(x)-1}{x} = -\frac{x}{2!} + \frac{x^3}{4!} - \frac{x^5}{6!} + \cdots}$$

The first three non-zero terms of above series are:

$$P_3(x) = \frac{-x}{2} + \frac{x^3}{24} - \frac{x^5}{720}$$




```
'''
Filename: e_3_b.py
Date Created: 10/09/2025
Created by: Archit Jain
Email: architj@uw.edu
Student No: 2426587
Description: Excercise 1-3: (b)
Compute the Taylor series expansion by hand for f (x).
For each function, plot f (x) = (cos(x) - 1)/x
and the three-term expansion (i.e., the first three nonzero terms) from x = -5 to
x = 5.
'''

# Importing libraries
import math                         # for math operations
import numpy as np                  # for arrays data storage
import matplotlib.pyplot as plt     # for plotting graphs
```

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```
# Define the function f(x)
def compute_f(x):
    '''
    A function that computes f(x) = (cos(x) - 1)/x for different values of x
    and also handles values where x=0 to be used as 0
    '''
    if x==0:
        # limit of (cos(x) - 1)/x as x->0 is 0
        return 0
    return (np.cos(x) - 1) / x

# Define the three-term Taylor expansion
def compute_taylor_expansion(x):
    '''
    A function that returns 3-term taylor expansion of f(x) = (cos(x) - 1)/x
    # P_3(x) = [(-x/2) + (x^3/4!) - (x^5/6!)]
    '''
    first_term = -1*x/2
    second_term = (x**3) / math.factorial(4)
    third_term = (x**5) / math.factorial(6)
    return first_term + second_term - third_term

# Setting a x array from -5->5 with 100 points from x=-5 to x=5
x_val = np.linspace(-5, 5, 100)

# Calculate y values for f(x) for each value of x
f_x = [compute_f(val) for val in x_val]
# Calculate the Three-term Taylor expansion
y_val = compute_taylor_expansion(x_val)

# Setting graph dimensions 10x8
plt.figure(figsize=(10, 8))
# Plotting points on graph
plt.plot(x_val, f_x, label='f(x) = (cos(x) - 1)/x', color='purple')
plt.plot(x_val, y_val, label='Taylor Expansion - Three-term', color='red', 
linestyle='--')
# Adding title and legends to graph plotted
plt.xlabel('x')
plt.ylabel('y')
plt.title('Excercise 1-3 (b)\nPlot of f(x) and its Three-term Taylor Expansion 
for function (cos(x) - 1)/x')
plt.legend()
# Show grid to the plot
plt.grid(True)
# Highlighting the origin lines
```

```
plt.axvline(0, color='gray', linestyle='-', linewidth=0.5)
plt.axhline(0, color='gray', linestyle='-', linewidth=0.5)
# Display the graph plotted
plt.show()
```

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Excercise 1-4: Please compute an analytic expression, by hand, for the real & imaginary parts of the following complex ~~numbers~~ functions.

(a) $f(t) = e^{it}$

$\Rightarrow$ As per Euler's formula for any real number x:

$e^{ix} = \cos(x) + i\sin(x)$

$\therefore$

$$\boxed{\begin{array}{l} f(t) = e^{it} = \cos(t) + i\sin(t) \\ \text{Real part} \Rightarrow \cos(t) \\ \text{Imaginary part} \Rightarrow \sin(t) \end{array}}$$

(b) $f(t) = e^{(1-i)t}$

$\Rightarrow f(t) = e^{(1-i)t} = e^{t-it} = e^{t}\cdot e^{-it}$

From Eulers formula, we get, (here $x = -t$)

$\therefore e^{-it} = \cos(-t) + i\sin(-t)$

$e^{-it} = \cos(t) - i\sin(t)$

$\therefore$

$$f(t) = e^{t}\cdot(\cos(t) - i\sin(t))$$

$\therefore$

$$\boxed{\begin{array}{l} f(t) = e^{t}\cos(t) - i(e^{t}\sin(t)) \\ \text{Real part} \Rightarrow e^{t}\cos(t) \\ \text{Imaginary part} \Rightarrow -e^{t}\sin(t) \end{array}}$$

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(c) $f(t) = e^{(-1-\pi i)t}$

$\Rightarrow f(t) = e^{-t-\pi i t} = e^{-t} \cdot e^{-\pi i t}$

using Eulers formula,

$e^{ix} = \cos(x) + i\sin(x)$

here, $x = -\pi t$

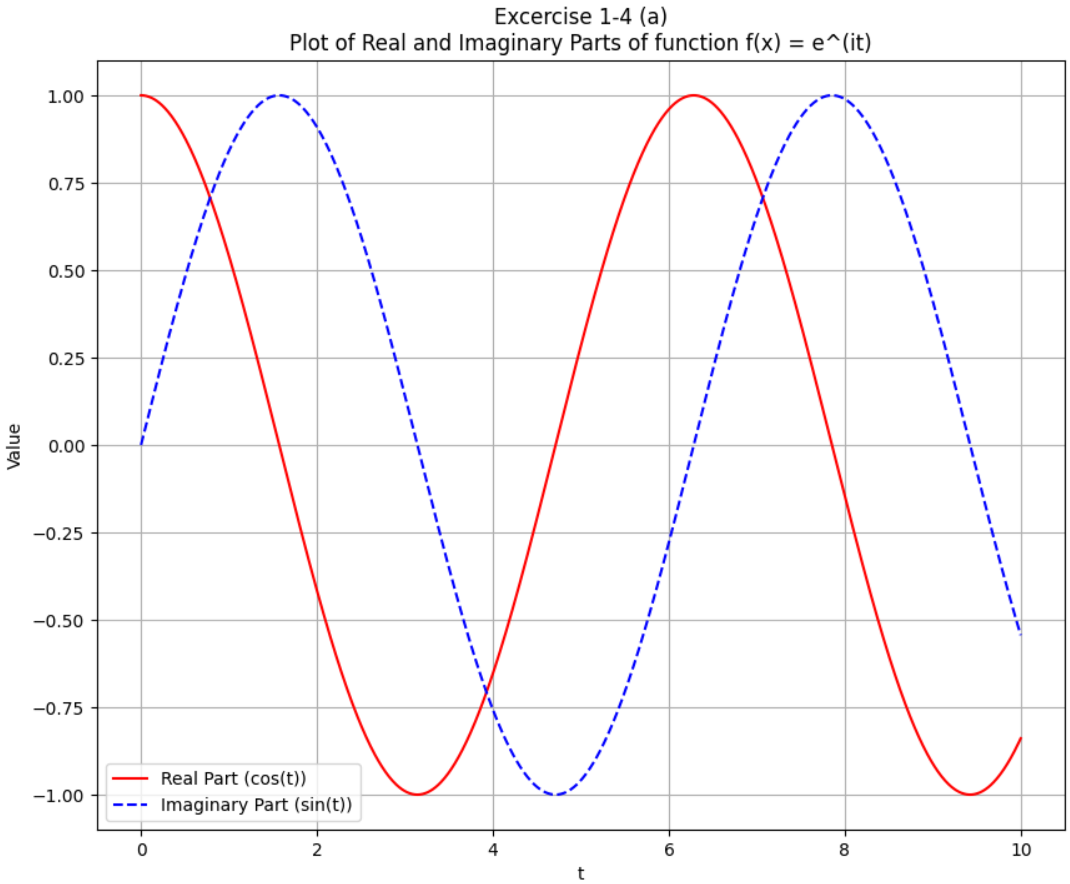
$\therefore e^{-\pi i t} = \cos(-\pi t) + i\sin(-\pi t) = \cos(\pi t) - i\sin(\pi t)$

$\therefore f(t) = e^{-t}\left(\cos(\pi t) - i\sin(\pi t)\right)$

$\therefore$ $\boxed{f(t) = e^{-t}\cos(\pi t) - i\left(e^{-t}\sin(\pi t)\right)}$

Real part $\rightarrow e^{-t}\cos(\pi t)$

Imaginary part $\rightarrow -e^{-t}\sin(\pi t)$




```
'''
Filename: e_4_a.py
Date Created: 10/09/2025
Created by: Archit Jain
Email: architj@uw.edu
Student No: 2426587
Description: Excercise 1-4: (a)
Please compute an analytic expression, by hand,
for the real and imaginary parts of the following complex functions.
Please also plot these for t = 0 : .01 : 10 where f (t) = e^it
'''

# Importing libraries
import numpy as np                    # for arrays data storage
import matplotlib.pyplot as plt      # for plotting graphs

# Setting a range for time from 0->10.01 with interval step size of 0.01
t = np.arange(0, 10.01, 0.01)
```

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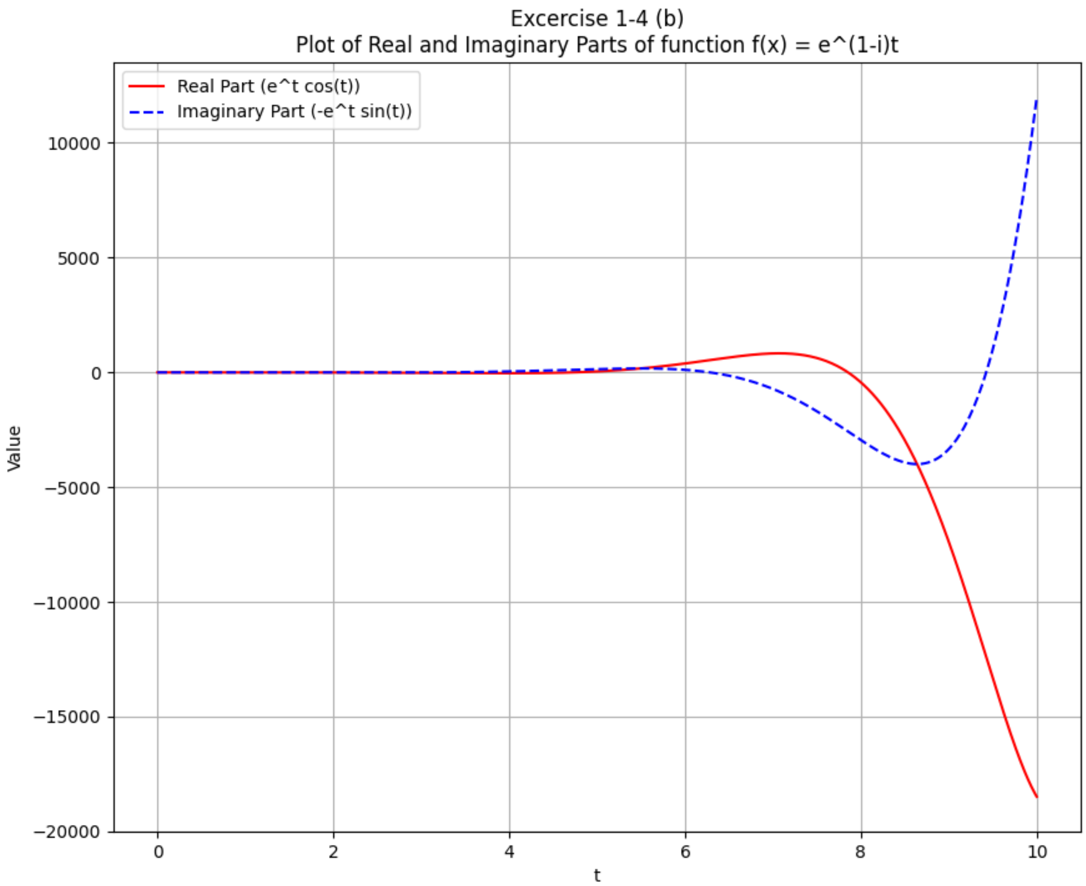
```
# Calculate the real and imaginary parts as f(t) = e^(i*t) = (cos(t)) + i(sin(t))
real_part = np.cos(t)
imaginary_part = np.sin(t)

# Setting graph dimensions 10x8
plt.figure(figsize=(10, 8))
# Plotting the real part on graph
plt.plot(t, real_part, label='Real Part (cos(t))', color='red')
# Plotting the imaginary part on graph
plt.plot(t, imaginary_part, label='Imaginary Part (sin(t))', color='blue',
linestyle='--')

# Adding title and legends to graph plotted
plt.xlabel('t')
plt.ylabel('Value')
plt.title('Excercise 1-4 (a)\nPlot of Real and Imaginary Parts of function f(x) =
e^(it)')
plt.legend()
# Show grid to the plot
plt.grid(True)
# Display the graph plotted
plt.show()
```




```python
'''
Filename: e_4_b.py
Date Created: 10/09/2025
Created by: Archit Jain
Email: architj@uw.edu
Student No: 2426587
Description: Excercise 1-4: (b)
Please compute an analytic expression, by hand,
for the real and imaginary parts of the following complex functions.
Please also plot these for t = 0 : .01 : 10 where f (t) = e^(1-i)t
'''

# Importing libraries
import numpy as np                    # for arrays data storage
import matplotlib.pyplot as plt      # for plotting graphs

# Setting a range for time from 0->10.01 with interval step size of 0.01
t = np.arange(0, 10.01, 0.01)
```

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```
# Calculate the real and imaginary parts as f(t) = e^(1-i)t = (e^t * cos(t)) -
i(e^t * sin(t))
real_part = np.exp(t) * np.cos(t)
imaginary_part = -np.exp(t) * np.sin(t)

# Setting graph dimensions 10x8
plt.figure(figsize=(10, 8))
# Plotting the real part on graph
plt.plot(t, real_part, label='Real Part (e^t cos(t))', color='red')
# Plotting the imaginary part on graph
plt.plot(t, imaginary_part, label='Imaginary Part (-e^t sin(t))', color='blue',
linestyle='--')

# Adding title and legends to graph plotted
plt.xlabel('t')
plt.ylabel('Value')
plt.title('Excercise 1-4 (b)\nPlot of Real and Imaginary Parts of function f(x) =
e^(1-i)t')
plt.legend()
# Show grid to the plot
plt.grid(True)
# Display the graph plotted
plt.show()
```

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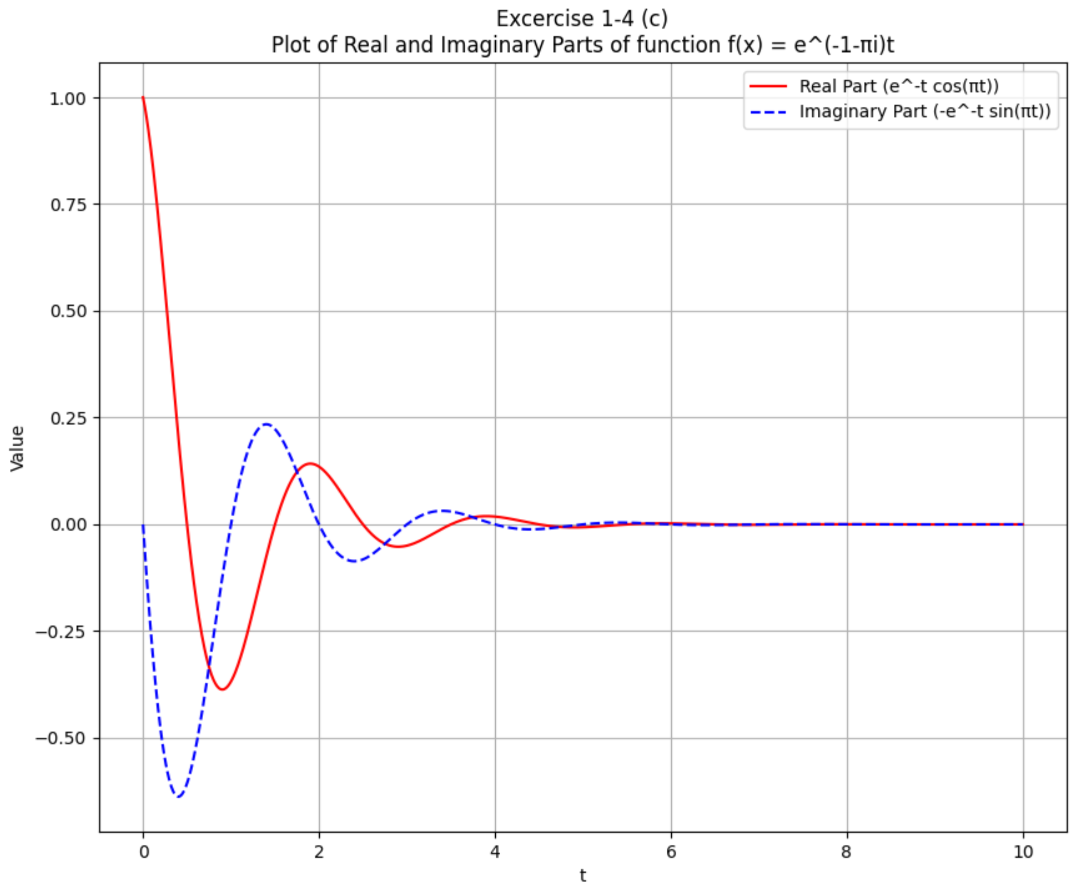


```
'''
Filename: e_4_c.py
Date Created: 10/09/2025
Created by: Archit Jain
Email: architj@uw.edu
Student No: 2426587
Description: Excercise 1-4: (c)
Please compute an analytic expression, by hand,
for the real and imaginary parts of the following complex functions.
Please also plot these for t = 0 : .01 : 10 where f (t) = e^(-1-πi)t
'''

# Importing libraries
import numpy as np                    # for arrays data storage
import matplotlib.pyplot as plt      # for plotting graphs

# Setting a range for time from 0->10.01 with interval step size of 0.01
t = np.arange(0, 10.01, 0.01)
```

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```python
# Calculate the real and imaginary parts as f(t) = e^(-1-πi)t = (e^-t * cos(πt))
- i(e^-t * sin(πt))
real_part = np.exp(-t) * np.cos(np.pi*t)
imaginary_part = -np.exp(-t) * np.sin(np.pi*t)

# Setting graph dimensions 10x8
plt.figure(figsize=(10, 8))
# Plotting the real part on graph
plt.plot(t, real_part, label='Real Part (e^-t cos(πt))', color='red')
# Plotting the imaginary part on graph
plt.plot(t, imaginary_part, label='Imaginary Part (-e^-t sin(πt))', color='blue',
linestyle='--')

# Adding title and legends to graph plotted
plt.xlabel('t')
plt.ylabel('Value')
plt.title('Excercise 1-4 (c)\nPlot of Real and Imaginary Parts of function f(x) =
e^(-1-πi)t')
plt.legend()
# Show grid to the plot
plt.grid(True)
# Display the graph plotted
plt.show()
```