

2.9.11

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Question

If \vec{a} and \vec{b} are unit vectors and θ is angle between them then prove that $\sin \frac{\theta}{2} = \frac{1}{2} |\vec{a} - \vec{b}|$

solution

Squaring on both sides,

$$\sin^2 \frac{\theta}{2} = \frac{1}{4} |\bar{a} - \bar{b}|^2$$

consider RHS,

$$\implies \frac{1}{4} |\bar{a} - \bar{b}|^2 \quad (1)$$

$$= \frac{1}{4} (|\bar{a}|^2 + |\bar{b}|^2 - 2\bar{a}^\top \bar{b}) \quad (2)$$

$$= \frac{1}{4} (2 - 2 \cos \theta) \quad (3)$$

$$= \frac{1}{2} (2 \sin^2 \frac{\theta}{2}) \quad (4)$$

$$(5)$$

Solution

$$= \sin^2 \frac{\theta}{2} \quad (6)$$

$$= LHS \quad (7)$$

$$\text{Hence, } \sin \frac{\theta}{2} = \frac{1}{2} |\bar{a} - \bar{b}|$$

C Code

```
#include <stdio.h>
#include <math.h>

double dot_product(double a[], double b[]) {
    return a[0]*b[0] + a[1]*b[1];
}

double norm(double v[]) {
    return sqrt(v[0]*v[0] + v[1]*v[1]);
}

void normalize(double v[]) {
    double n = norm(v);
    if (n != 0) {
        v[0] /= n;
        v[1] /= n;
    }
}
```

```
int main() {  
    double a[2] = {1, 2};  
    double b[2] = {2, 1};  
  
    normalize(a);  
    normalize(b);  
  
    double cos_theta = dot_product(a, b);  
    double theta = acos(cos_theta);  
  
    double diff[2] = {0.5 * (a[0] - b[0]), 0.5 * (a[1] - b[1])};  
    double lhs = norm(diff);  
}
```

```
double rhs = sin(theta / 2.0);

    printf("Angle (in degrees): %.6f\n", theta * (180.0 / M_PI))
    ;
    printf("||0.5(a - b)|| = %.6f\n", lhs);
    printf("sin( / 2) = %.6f\n", rhs);
    printf("Difference = %.6e\n", fabs(lhs - rhs));

return 0;
}
```

```
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.patches import Arc

def plot_vectors_with_angle(a, b):
    a = np.array(a)
    b = np.array(b)

    # Calculate angle (in radians and degrees)
    dot_product = np.dot(a, b)
    norm_a = np.linalg.norm(a)
    norm_b = np.linalg.norm(b)
    cos_theta = dot_product / (norm_a * norm_b)
    theta_rad = np.arccos(np.clip(cos_theta, -1.0, 1.0))
    theta_deg = np.degrees(theta_rad)
```



```
# Setup plot
fig, ax = plt.subplots()
ax.set_aspect('equal')
ax.grid(True)

# Calculate plot limits
max_val = max(np.linalg.norm(a), np.linalg.norm(b)) + 1
ax.set_xlim(-1, max_val)
ax.set_ylim(-1, max_val)

# Plot vectors
origin = [0, 0]
ax.quiver(*origin, *a, angles='xy', scale_units='xy', scale
          =1, color='r', label='a')
ax.quiver(*origin, *b, angles='xy', scale_units='xy', scale
          =1, color='b', label='b')
```

```
# Draw angle arc
arc_radius = 0.5
arc = Arc(origin, arc_radius*2, arc_radius*2, angle=0,
          theta1=0, theta2=theta_deg, color='green')
ax.add_patch(arc)

# Annotate angle
mid_angle = theta_rad / 2
label_radius = arc_radius * 1.4
x_text = label_radius * np.cos(mid_angle)
y_text = label_radius * np.sin(mid_angle)
ax.text(x_text, y_text, f' = {theta_deg:.1f}', fontsize=12,
       color='green')
```

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```

```
# Labels and title
ax.legend()
ax.set_xlabel('X-axis')
ax.set_ylabel('Y-axis')
ax.set_title('Angle Between Vectors a and b')
plt.show()
```

```
# Example usage with any two 2D vectors:
```

```
# Replace these with your own vectors
```

```
a = [3, 2]
```

```
b = [2, 4]
```

```
plot_vectors_with_angle(a, b)
```

C and Python Code

```
import ctypes
import numpy as np
import platform
import os

# Load C shared library
if platform.system() == 'Windows':
```

```
lib = ctypes.CDLL('./vector_math.dll')
else:
    lib = ctypes.CDLL('./libvector.so')
# Define argtypes and restype
lib.half_diff_norm.argtypes = [ctypes.c_double]*4
lib.half_diff_norm.restype = ctypes.c_double
lib.sin_theta_over_2.argtypes = [ctypes.c_double]
lib.sin_theta_over_2.restype = ctypes.c_double
# Define two vectors (they will be normalized in Python)
a = np.array([1, 2], dtype=np.float64)
b = np.array([2, 1], dtype=np.float64)
# Normalize
a_hat = a / np.linalg.norm(a)
b_hat = b / np.linalg.norm(b)
```

C and Python Code

```
# Compute dot product
dot_ab = np.dot(a_hat, b_hat)

# Call C functions
lhs = lib.half_diff_norm(a_hat[0], a_hat[1], b_hat[0], b_hat[1])
rhs = lib.sin_theta_over_2(dot_ab)

# Show results
print(f'||0.5(a - b)|| = {lhs:.6f}')
print(f'sin( / 2) = {rhs:.6f}')
print(f'Difference = {abs(lhs - rhs):.6e}')

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