1.2.24

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Question

Rain is falling vertically with a speed of 35 m/s. Wind starts blowing after some time with a speed of 12 m/s in the east to west direction. In which direction should a boy waiting at a bus stop hold his umbrella?

Theoretical Solution

Let,

$\mathbf{v}_{r/w}$ be the velocity of rain relative to the wind (downward),

$$\mathbf{v}_{r/w} = \begin{pmatrix} 0 \\ -35 \end{pmatrix}$$

.

$\mathbf{v}_w$ be the velocity of wind relative to ground

$$\mathbf{v}_w = \begin{pmatrix} -12 \\ 0 \end{pmatrix}$$

.

$\mathbf{v}_r$ be the velocity of rain relative to ground Take $+x$ to the east and $+y$ upward.

Resultant rain velocity (relative to ground).

$$\mathbf{v}_r = \mathbf{v}_w + \mathbf{v}_{r/w} \tag{1}$$

Let θ be the angle between $\mathbf{v}_r$ and the downward vertical unit vector

$$\hat{\ } \quad \begin{pmatrix} 0 \end{pmatrix}$$

Theoretical Solution

Using the dot product,

$$\cos\theta = \frac{\mathbf{v}_r \cdot \hat{u}_{\downarrow}}{\left\|\mathbf{v}_r\right\|} \tag{2}$$

$$\cos\theta = \frac{v_{r/w}}{\sqrt{v_{r/w}^2 + v_w^2}} \tag{3}$$

Equation 3 is obtained by substituting Equation 1 in Equation 2

Theoretical Solution

Substitute given values.

For this problem, the speed of rain w.r.t wind is $v_{r/w} = 35$ m/s the wind speed is $v_w = 12$ m/s (east to west).

$$\cos\theta = \frac{35}{\sqrt{35^2 + 12^2}} \tag{4}$$

$$\cos\theta = \frac{35}{37} \tag{5}$$

$$\theta = \cos^{-1}\left(\frac{35}{37}\right) \tag{6}$$

Conclusion

Rain falls at an angle of $\theta = \cos^{-1}\left(\frac{35}{37}\right)$ west of vertical downward
The rain's velocity component is toward the west and downward, so the umbrella must be kept in the opposite direction:
Hence,

$$\text{Umbrella direction should be at an angle} \cos^{-1}\left(\frac{35}{37}\right) \text{ east of vertical upward.} \tag{7}$$

C Code

```
#include <math.h>
#include<stdio.h>
// Function to compute umbrella angle (in radians)
// vrw = velocity of rain relative to wind (2D vector)
// vw = velocity of wind relative to ground (2D vector)
double umbrella_angle(double vrw[2], double vw[2]) {
    // Step 1: Resultant rain velocity relative to ground
    double vr[2];
    vr[0] = vw[0] + vrw[0];
    vr[1] = vw[1] + vrw[1];

    // Step 2: Downward unit vector
    double u_{down}[2] = {0.0, -1.0};
```

C Code

```c
    // Step 3: Dot product
    double dot = vr[0]*u_down[0] + vr[1]*u_down[1];

    // Step 4: Norm of vr
    double norm_vr = sqrt(vr[0]*vr[0] + vr[1]*vr[1]);

    // Step 5: Angle from vertical (acos of normalized dot
        product)
    return acos(dot / norm_vr); // radians
```

Python+C code

```
import ctypes
import numpy as np
import matplotlib.pyplot as plt
import math
import os

# ---- load the shared library (must be in same folder) ----
lib_path = ./umbrella.so


lib = ctypes.CDLL(lib_path)
lib.umbrella_angle.argtypes = [ctypes.c_double * 2, ctypes.
    c_double * 2]
lib.umbrella_angle.restype = ctypes.c_double
```

Python+C code

```
vrw_np = np.array([0.0, -35.0]) # rain relative to wind (x east,
    y up)
vw_np = np.array([-12.0, 0.0]) # wind (east->west is -12)

# prepare ctypes arrays and call C function
vrw_ct = (ctypes.c_double * 2)(*vrw_np)
vw_ct = (ctypes.c_double * 2)(*vw_np)

theta = lib.umbrella_angle(vrw_ct, vw_ct) # radians returned from
     C
theta_deg = math.degrees(theta)

printf(Angle from vertical (radians): {theta:.6f})
printf(Angle from vertical (degrees): {theta_deg:.3f})
```

Python+C code

```
# ---- prepare plotting data ----
v_r = vrw_np + vw_np # resultant rain velocity (ground frame)
umbrella_dir = -v_r # umbrella points opposite to rain motion
# scale umbrella arrow so it's visible on the plot (preserve
    direction)
if np.linalg.norm(umbrella_dir) > 0:
    umbrella_vis = umbrella_dir / np.linalg.norm(umbrella_dir) *
        20.0
else:
    umbrella_vis = np.array([0.0, 0.0])

# ---- plotting ----
fig, ax = plt.subplots(figsize=(7,7))
```

Python+C code

```python



ax.quiver(0, 0, vrw_np[0], vrw_np[1], angles='xy', scale_units='xy', scale=1,
        color='tab:blue', width=0.006, label=r'$\vec v_{r/w}=(0,-35)$')
ax.quiver(0, 0, vw_np[0], vw_np[1], angles='xy', scale_units='xy', scale=1,
        color='tab:green', width=0.006, label=r'$\vec v_w=(-12,0)$')
ax.quiver(0, 0, v_r[0], v_r[1], angles='xy', scale_units='xy', scale=1,
        color='tab:red', width=0.006, label=r'$\vec v_r$ (resultant)')
```

Python+C code

```
# umbrella direction (longer, visible)
ax.quiver(0, 0, umbrella_vis[0], umbrella_vis[1], angles='xy',
    scale_units='xy', scale=1,
          color='tab:purple', width=0.01, label='Hold umbrella (
              into rain)')

# dashed vertical reference (downward)
ax.plot([0, 0], [0, -45], linestyle=':', color='gray', linewidth
    =1)

# annotate angle value near origin
ax.text(0.5, -8, f = {theta_deg:.1f} from vertical, fontsize=12,
        bbox=dict(facecolor='white', alpha=0.8, edgecolor='gray')
            )
```

Python+C code

```
# axis limits and labels
ax.set_xlim(-40, 10)
ax.set_ylim(-50, 10)
ax.set_aspect('equal', 'box')
ax.set_xlabel(x-axis (East-West) (m/s))
ax.set_ylabel(y-axis (Up-Down) (m/s))
ax.set_title(Rain & Wind: Resultant Velocity and Umbrella
    Direction)
ax.grid(True, linestyle='--', linewidth=0.6)
ax.legend(loc='upper right')

# Save as PDF

plt.savefig(/sdcard/Matrix/ee1030-2025/ai25btech11016/Matgeo
    /1.2.24/figs/1.2.24.png, bbox_inches='tight')
plt.show()
```

Python plot code

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

# Given speeds (m/s)
v_rain_down = 35 # rain relative to air (vertical down)
v_wind_ew = 12 # wind from East to West (negative x)

# Vectors (x to East, y to North)
v_rw = np.array([0, -v_rain_down]) # rain wrt wind/air
v_w = np.array([-v_wind_ew, 0]) # wind wrt ground
v_r = v_rw + v_w # rain wrt ground (what we feel)

# Angle of tilt from vertical (in degrees)
theta = np.degrees(np.arctan2(abs(v_w[0]), abs(v_rw[1]))) # =
    arctan(12/35)
```

Python plot code

```
# Plot
fig, ax = plt.subplots(figsize=(7,7))
ax.set_aspect('equal', 'box')
ax.grid(True, linestyle='--', linewidth=0.6)
ax.set_xlim(-45, 15)
ax.set_ylim(-50, 15)

# Axes labels/title
ax.set_xlabel('East  (m/s)')
ax.set_ylabel('North  (m/s)')
ax.set_title('Rain & Wind: Resultant Velocity and Umbrella
    Direction')
```

Python plot code

```python
# Draw vectors from origin
def arrow(v, color, label):
    ax.quiver(0, 0, v[0], v[1], angles='xy', scale_units='xy',
        scale=1,
              width=0.007, color=color, label=label)

arrow(v_rw, 'tab:blue', r'$\vec v_{r/w}=(0,-35)$')
arrow(v_w, 'tab:orange', r'$\vec v_{w}=(-12,0)$')
arrow(v_r, 'tab:red', r'$\vec v_{r}=(-12,-35)$')

# Umbrella should be held opposite to rain's motion (i.e., into
    the apparent rain)
arrow(-v_r, 'tab:green', 'Hold umbrella this way')
```

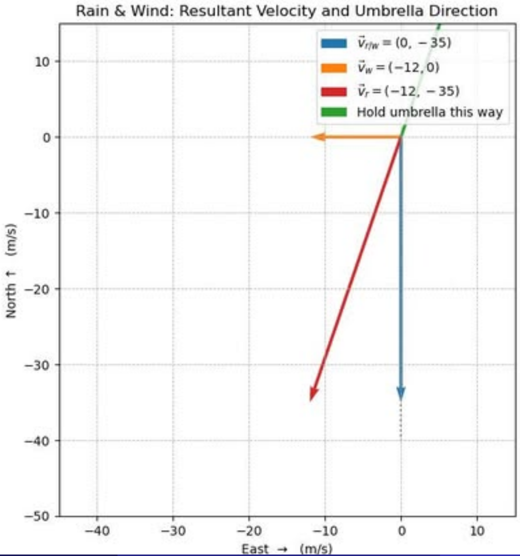
Python plot code

```python
# Annotate deflection angle from vertical
ax.annotate(fr'$\theta=\arctan\!\left(\frac{{12}}{{35}}\right)\approx{theta:.1f}^\circ$',
            xy=(0,0), xytext=(-6,-5), textcoords='offset points',
            fontsize=11, bbox=dict(boxstyle='round,pad=0.3', fc='white', ec='gray', alpha=0.8))

# Reference vertical (dashed) to show tilt
ax.plot([0,0], [0,-40], linestyle=':', color='gray')

ax.legend(loc='upper right')
plt.savefig(/sdcard/Matrix/ee1030-2025/ai25btech11016/Matgeo/1.2.24/figs/1.2.24.png)
plt.show()
```

Plot



Rain & Wind: Resultant Velocity and Umbrella Direction
$\vec{v}_{r/w} = (0, -35)$
$\vec{v}_w = (-12, 0)$
$\vec{v}_r = (-12, -35)$
Hold umbrella this way
North ↑ (m/s)
East → (m/s)
10
0
−10
−20
−30
−40
−50
−40
−30
−20
−10
0
10