

**The Islamic University of Gaza
Faculty of Engineering
Civil Engineering Department**

**Environmental Engineering
(ECIV 4324)**

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Meteorology and Air Pollution

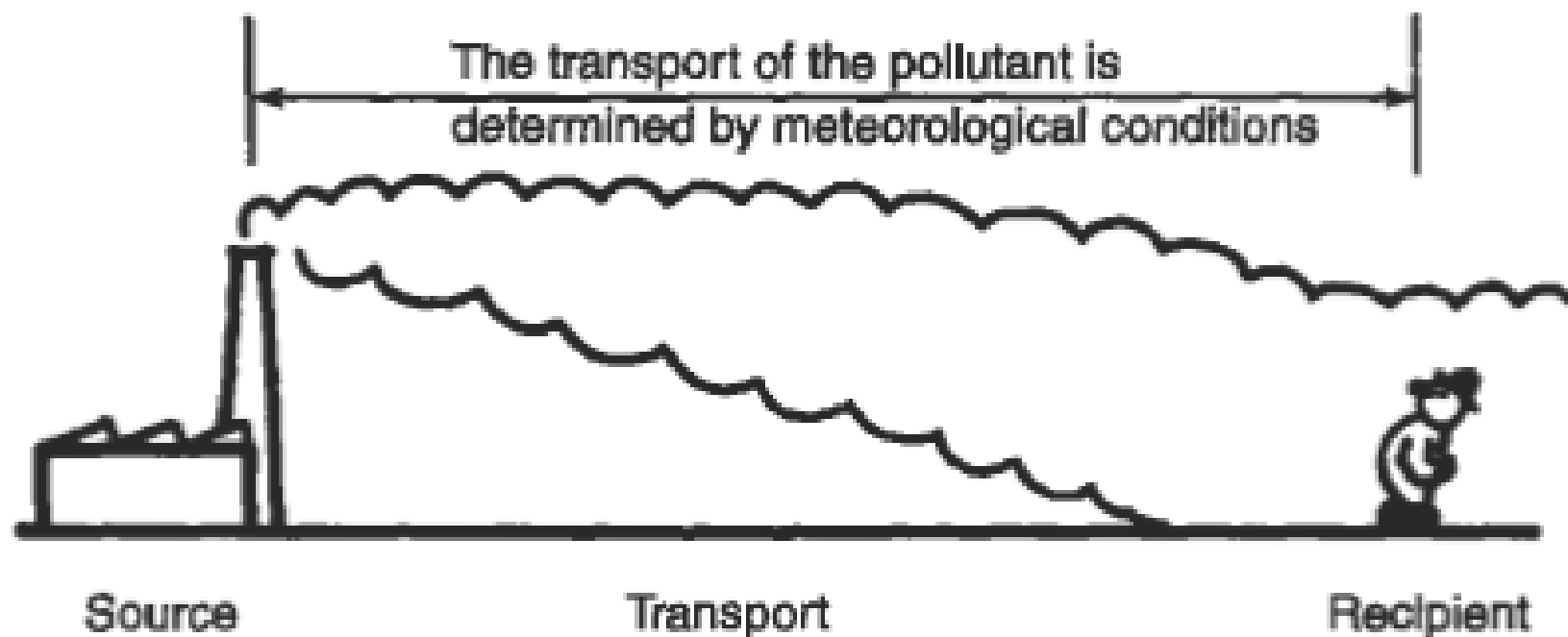
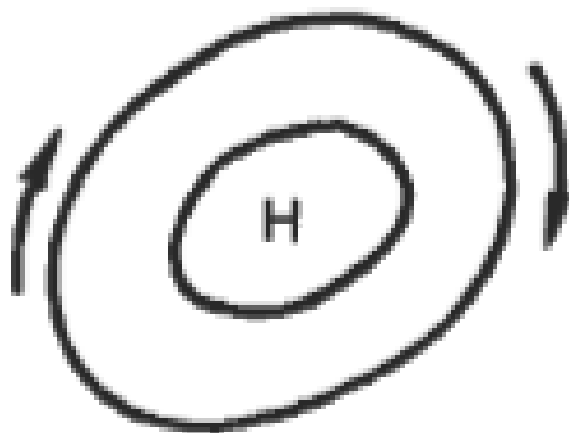
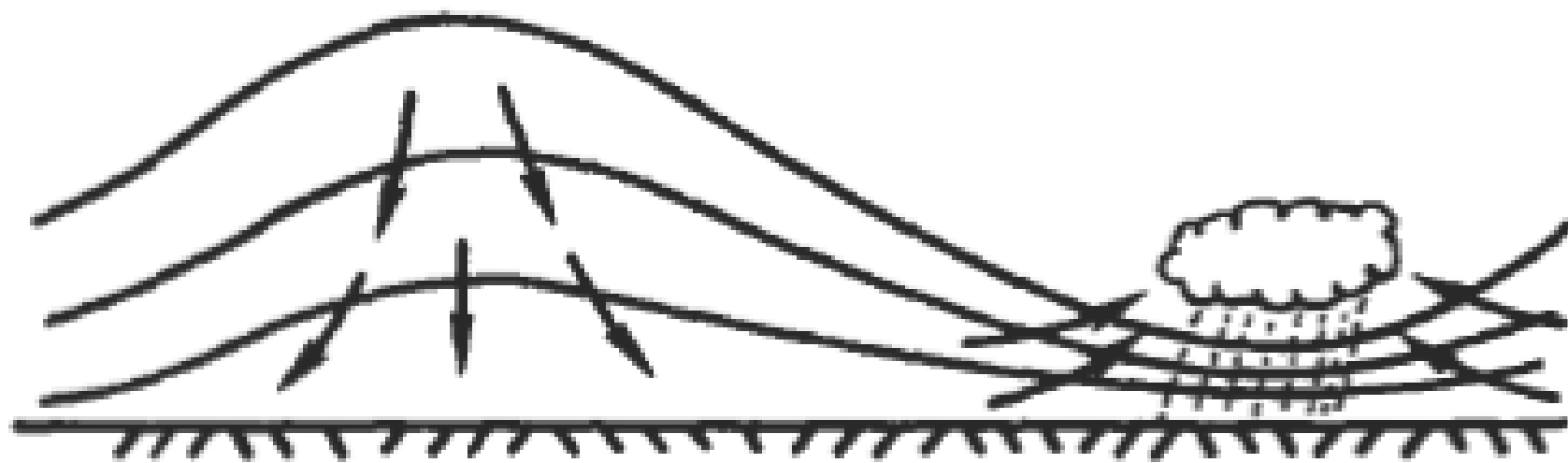
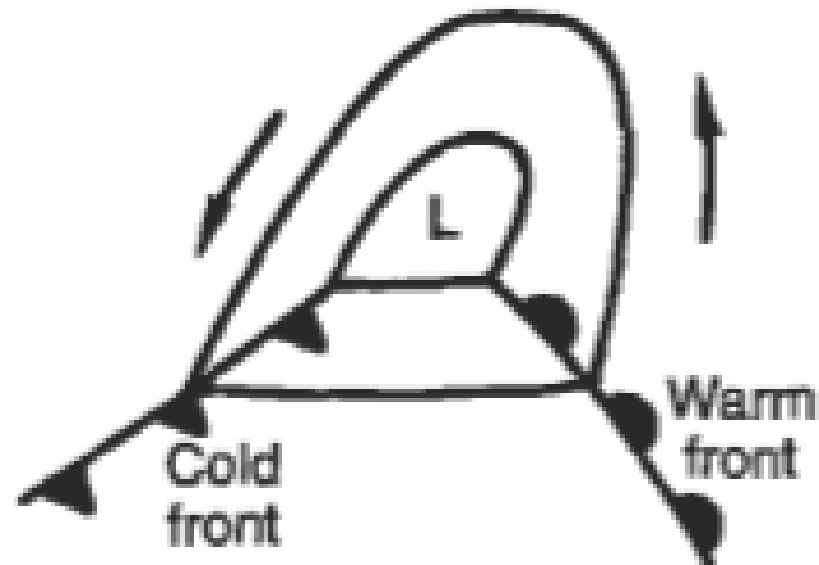


Figure 18-1. Meteorology of air pollutants.



Anticyclone



Cyclone

Figure 18-2. Anticyclone and cyclone.

HORIZONTAL DISPERSION OF POLLUTANTS

The earth receives light energy at high frequency from the sun and converts this to heat energy at low frequency, which is then radiated back into space. Heat is transferred from the **earth's surface by radiation, conduction, and convection**

Radiation is direct transfer of energy and has little effect on the atmosphere; conduction is the transfer of heat by physical contact (the atmosphere is a poor conductor since the air molecules are relatively far apart)

convection is transfer of heat by movement of warm air masses. Solar radiation warms the earth and thus the air above it. This heating is most effective at the equator and least at the poles. The warmer, less dense air rises at the equator and cools, becomes more dense, and sinks at the poles. If the earth did not rotate then the surface wind pattern would be from the poles to the equator. However, the rotation of the earth continually presents new surfaces to be warmed, so that a horizontal air pressure gradient exists as well **as the vertical pressure gradient. The** resulting motion of the **air creates a pattern of winds around the globe, as shown**

Seasonal and local temperature, pressure and cloud conditions, and local topography complicate the picture. Land masses heat and cool faster than water so that shoreline winds blow out to sea at night and inland during the day. Valley winds result from cooling of air high on mountain slopes. In cities, brick and concrete buildings absorb heat during the day and radiate it at night, creating a ***heat island*** which sets up a self-contained circulation called a haze ***hood from which pollutants*** cannot escape.

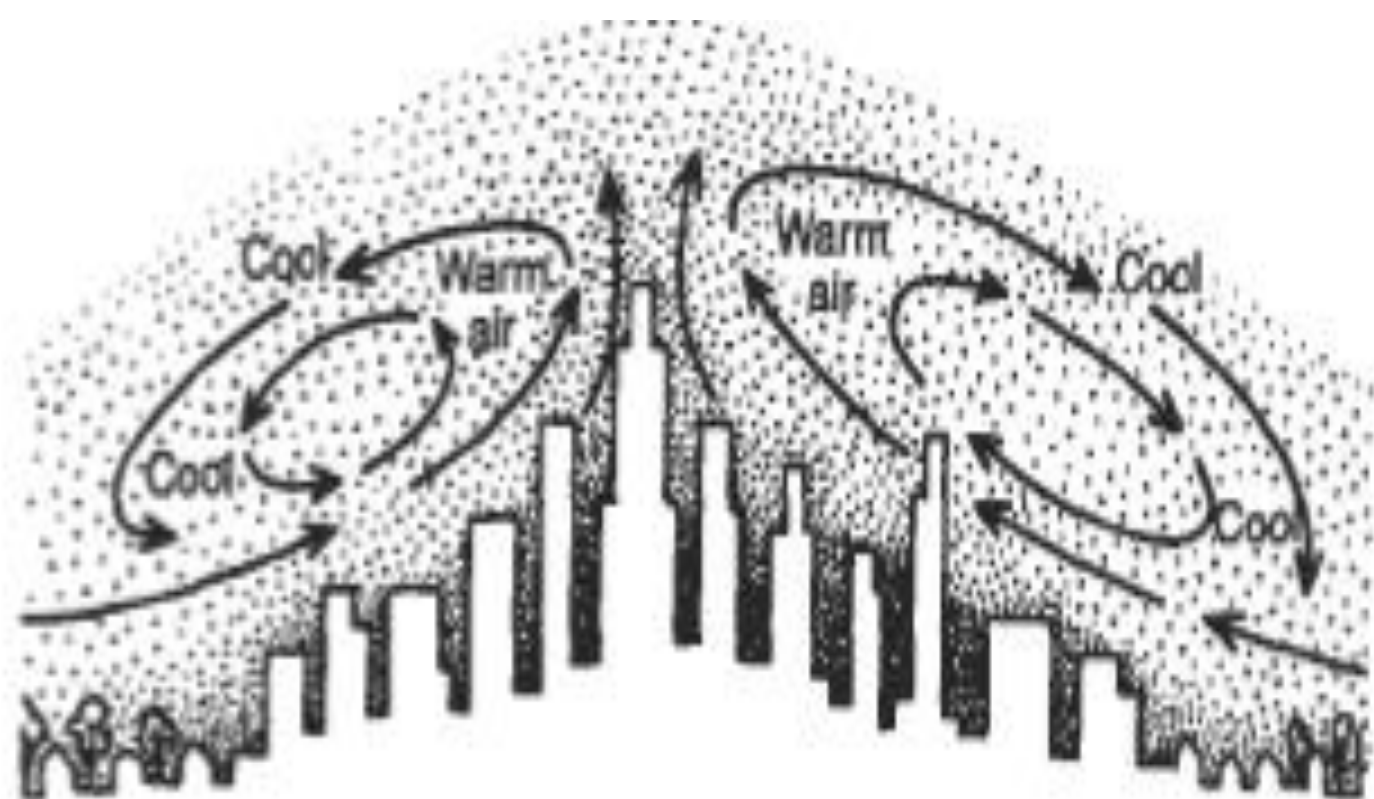


Figure 18-5. Heat island formed over a city.

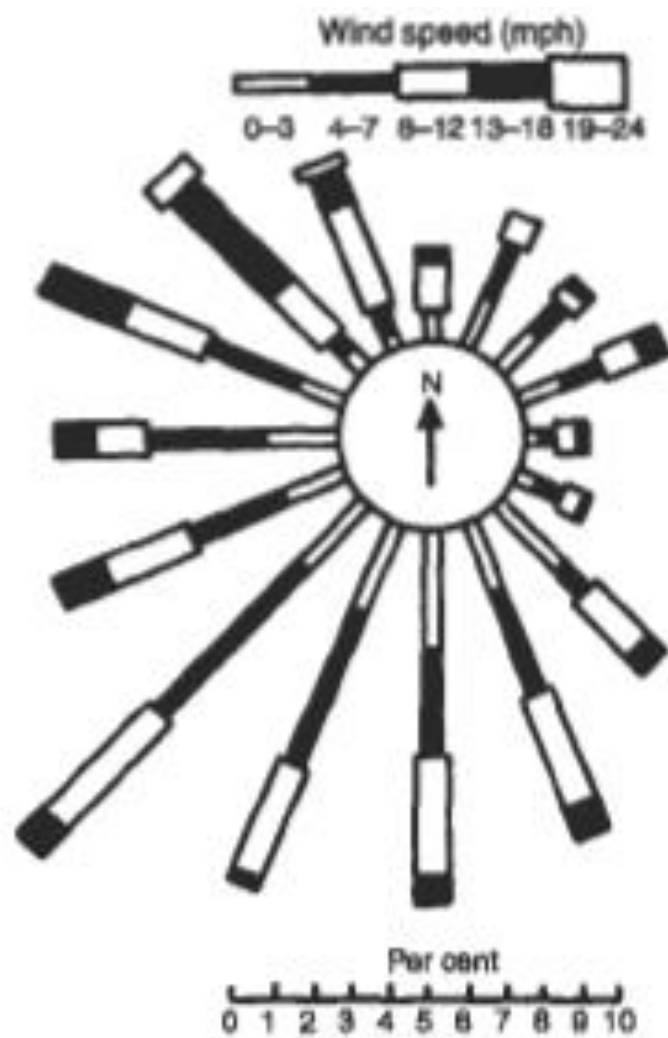


Figure 18-6. Typical wind rose.

VERTICAL DISPERSION OF POLLUTANTS

$$dT/dz|_{\text{dry-adiabatic}} = -9.8^{\circ}\text{C/km},$$

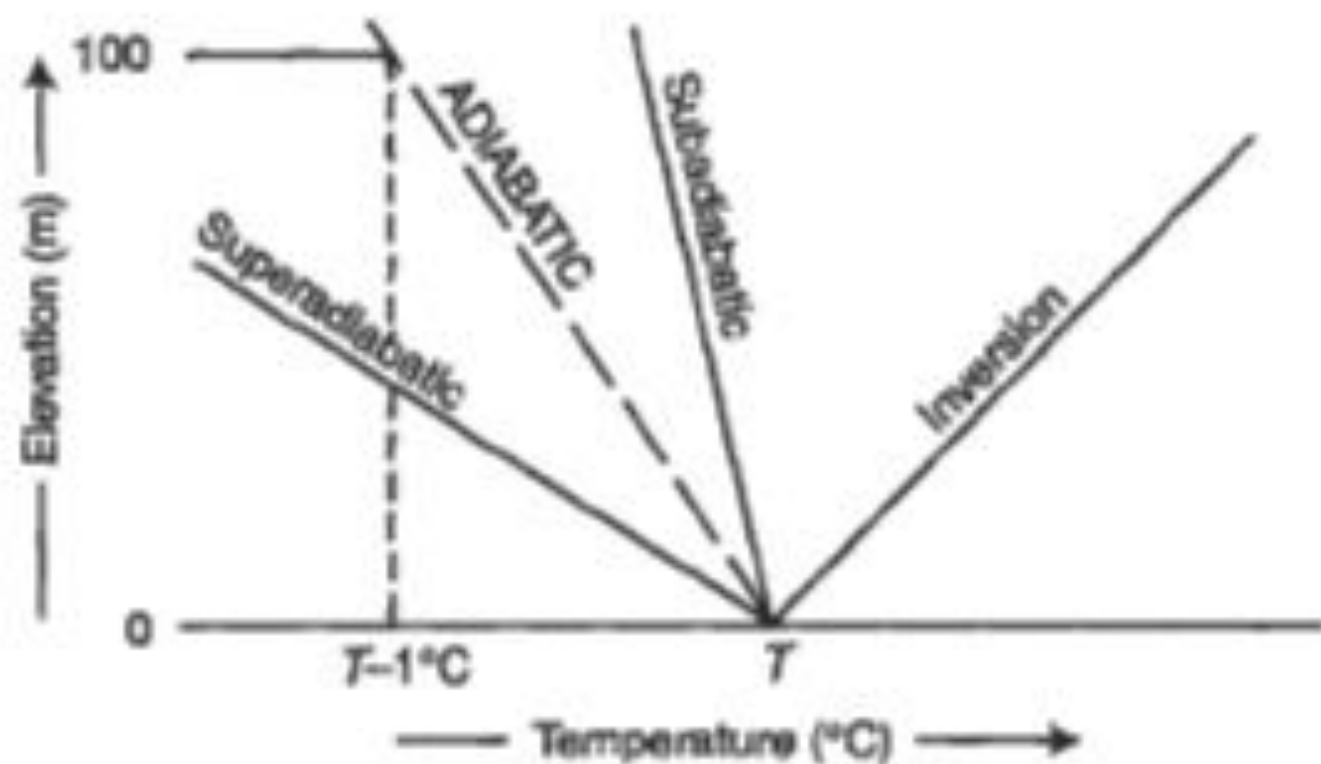
where T = temperature and z = altitude.

VERTICAL DISPERSION OF POLLUTANTS

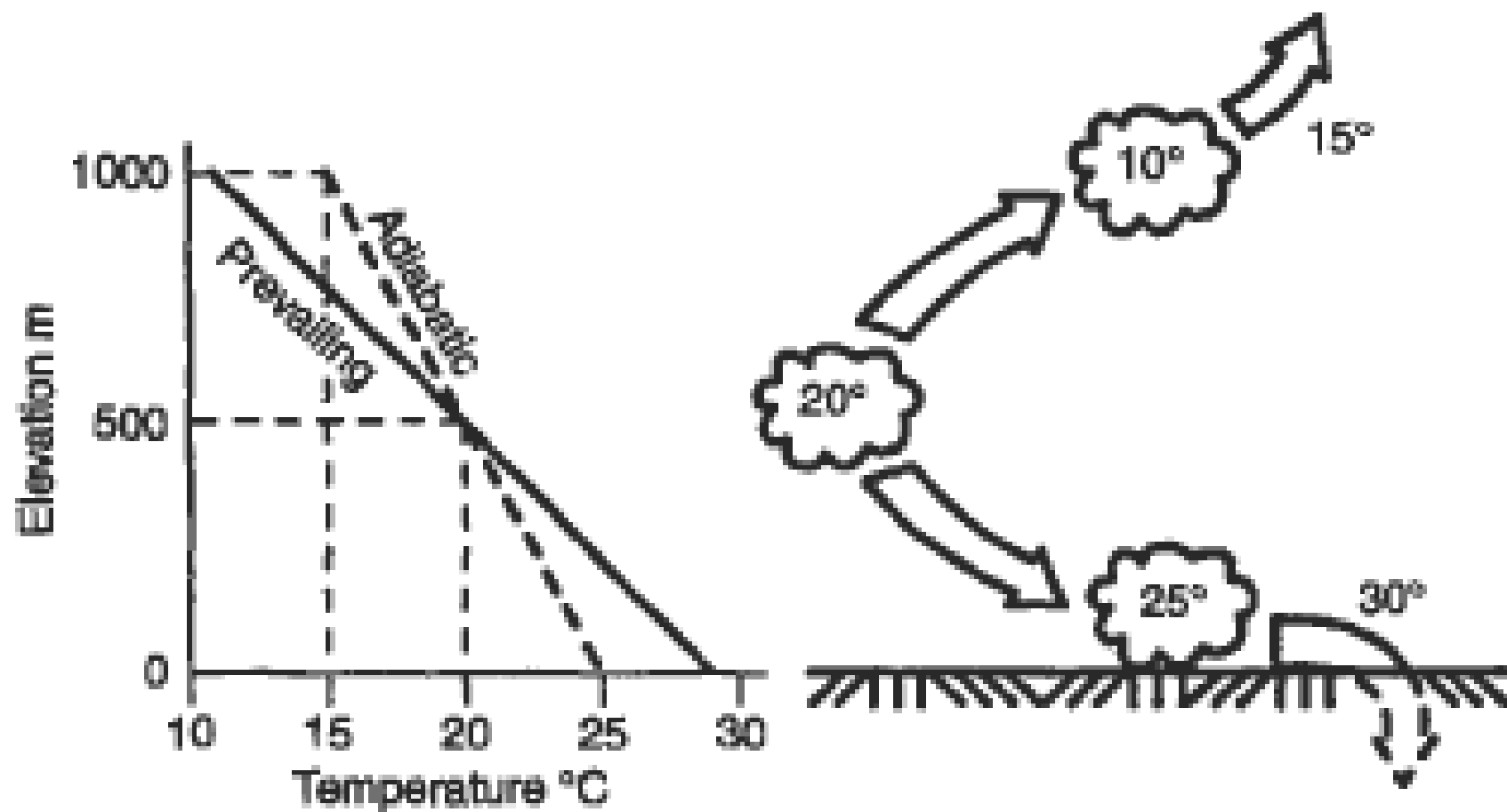
The actual measured rate at which **air cools as it rises is called the *ambient or prevailing lapse rate*. The relationships between the *ambient lapse rate* and *the dry*** adiabatic lapse rate essentially determine the stability of the air and the speed with which pollutants will disperse

When the ambient lapse rate is exactly the same as the *dry adiabatic lapse rate*, the atmosphere has ***neutral stability***. ***Super adiabatic conditions prevail when the air*** temperature drops more than ***9.80C/h (10C/100m)***. ***Sub adiabatic conditions prevail*** when the air temperature drops at a rate less than ***9.80C/h***.

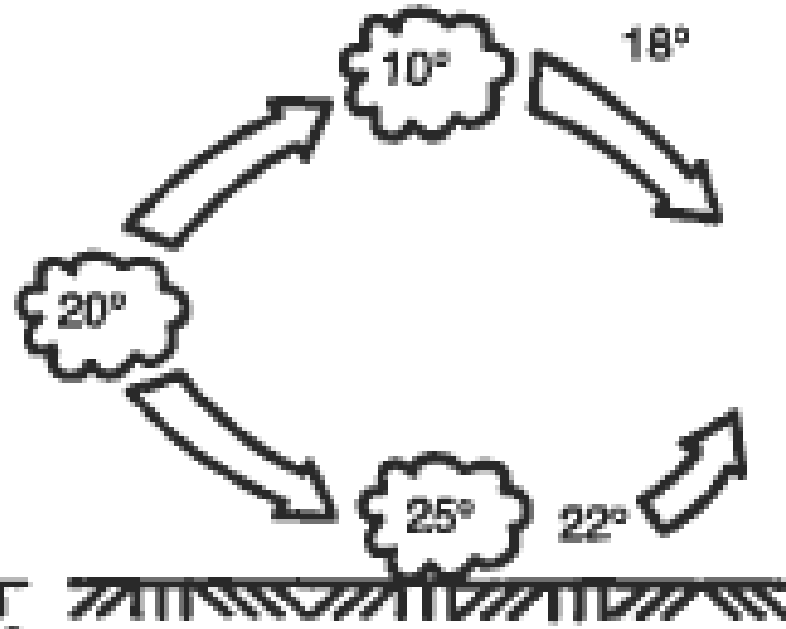
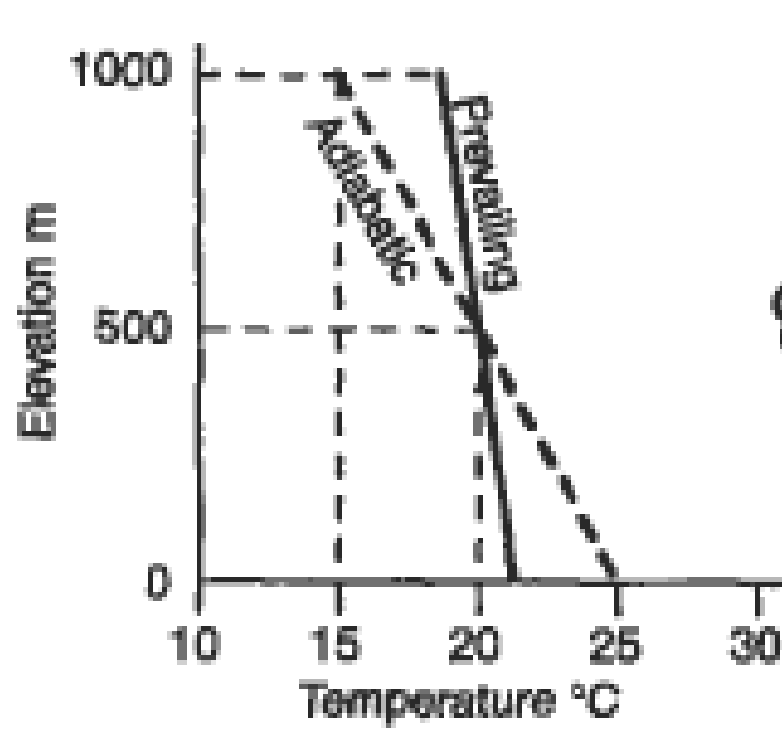
A special case of Sub adiabatic conditions is the ***temperature inversion, when the air temperature actually*** increases with altitude and a layer of ***warm air exists over a layer of cold air.*** Superadiabatic atmospheric conditions are unstable and favor dispersion; subadiabatic conditions are stable and result in poor dispersion; inversions are extremely stable and trap pollutants, inhibiting dispersion



re 18-8. Ambient lapse rates and the dry adiabatic lapse rate.



A. Super-adiabatic conditions (unstable)



B. Sub-adiabatic conditions (stable)

The air temperature at **an elevation of 500 m is 20°C, and the atmosphere is superadiabatic:** the ground level temperature is 30°C and the temperature at an elevation of 1 km is 10°C. The (superadiabatic) ambient lapse rate is -20°C/km. If a parcel of air at 500 m moves up adiabatically to 1 km, what will be its temperature? According to the *dry adiabatic lapse rate of - 9 . 8 °C/km the air parcel would cool by 4.9°C to about 15°C.*

However, the temperature at 1 km is not 15°C but 10°C. Our air parcel is 5°C warmer than the surrounding air and will continue to **rise**. **In short, under subadiabatic** conditions, a rising parcel of air keeps right on going up. Similarly, if our parcel were displaced downward to, say, **250m, its temperature would increase by 2.5°C to 22.5°C.**

The ambient temperature at 250 m, however, is 25°C, so that our parcel of air is now ***cooler than the surrounding air and keeps on sinking. There is no tendency to stabilize;*** conditions favor instability

Now let us suppose that the ground level temperature is 22°C , and the temperature at an elevation of 1 km is 15°C . The (subadiabatic) ambient lapse rate is now $-7^{\circ}\text{C}/\text{km}$.

If our parcel of air at 500 m moves up adiabatically to 1 km, its temperature would again drop by 4.9°C to about 15°C the same as the temperature of the surrounding air at 1 km. Our *air parcel would cease rising, since it would be at the same density as the surrounding air*.

If the parcel were to sink to **250 m**, its **temperature would again be 22.5°C**, and the ambient temperature would be a little more than **20°C**. **The air parcel is slightly** warmer than the surrounding air and tends to rise back to where it was. In other words, its vertical motion is damped, and it tends to become stabilized, subadiabatic conditions favor stability and limit vertical mixing.

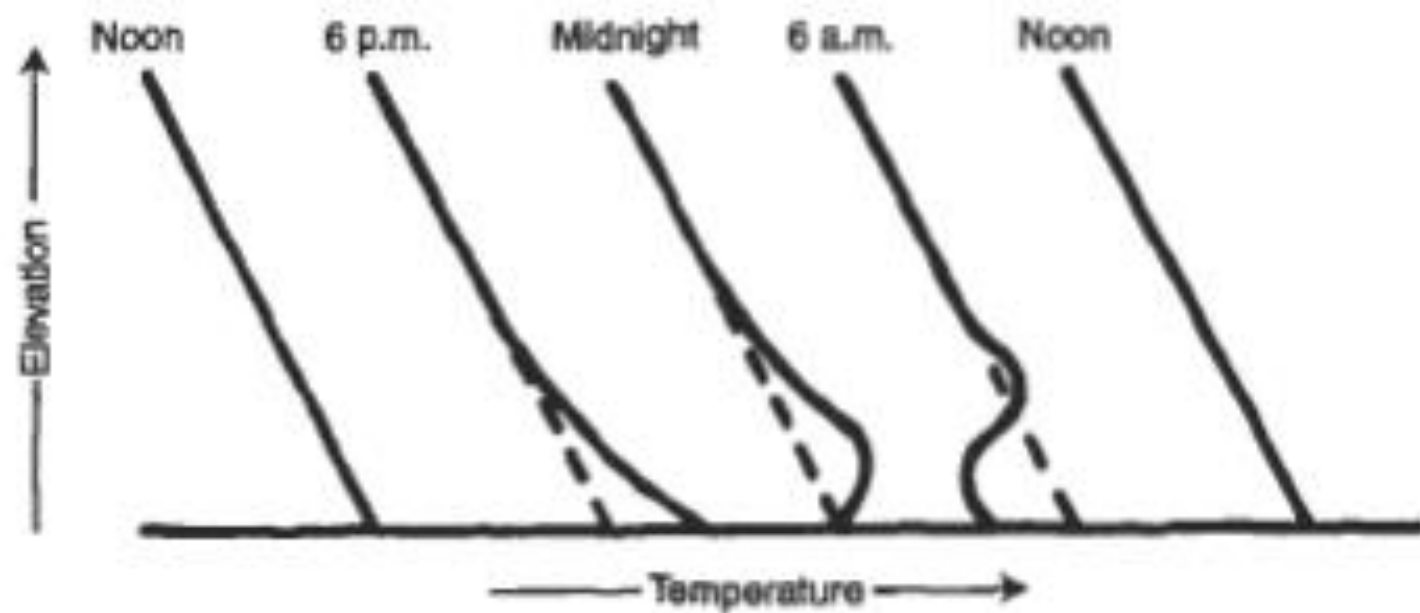


Figure 18-11. Typical ambient lapse rates during a sunny day and clear night.



Inversion



Fanning plume



Inversion over
superadiabatic



Fumigation

Figure 18-12. Plume shapes and atmospheric stability.



Superadiabatic



Looping plume



Adiabatic



Coring plume

EXAMPLE 18.1. A stack 100 m tall emits a plume whose temperature is 20°C . The temperature at the ground is 19°C . The ambient lapse rate is $-4.5^{\circ}\text{C}/\text{km}$ up to an altitude of 200 m. Above this the ambient lapse rate is $+20^{\circ}\text{C}/\text{km}$. Assuming perfectly adiabatic conditions, how high will the plume rise and what type of plume will it be?

Figure 18-14 shows the various lapse rates and temperatures. The plume is assumed to cool at the dry adiabatic lapse rate $10^{\circ}\text{C}/\text{km}$. The ambient lapse rate below 200 m is subadiabatic, the surrounding air is cooler than the plume, so it rises, and cools as it rises. At 225 m, the plume has cooled to 18.7°C , but the ambient air is at this temperature also, and the plume ceases to rise. Below 225 m, the plume would have been slightly coning. It would not have penetrated 225 m.

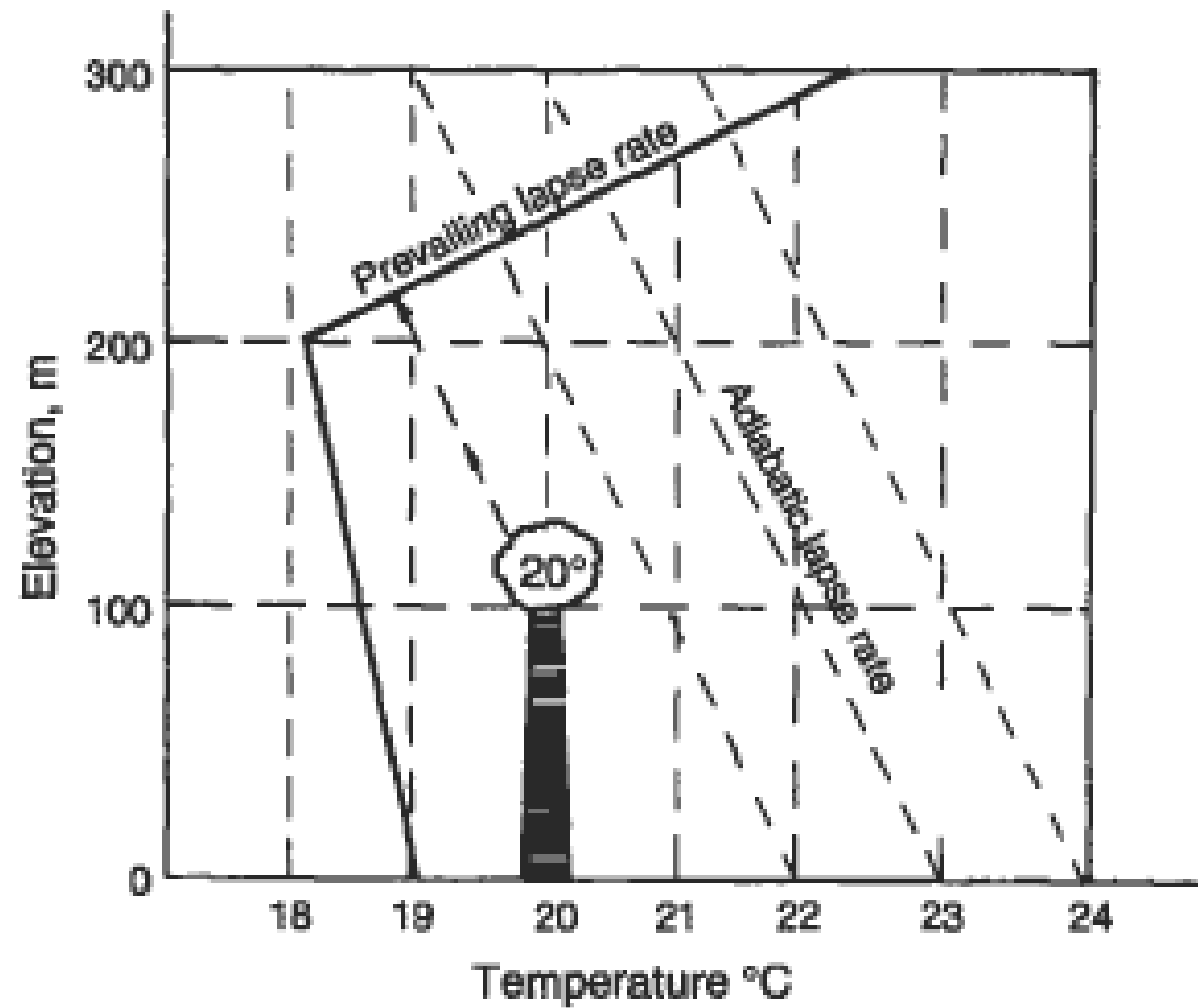


Figure 18-14. Atmospheric conditions in Example 18.1.

ATMOSPHERIC DISPERSION

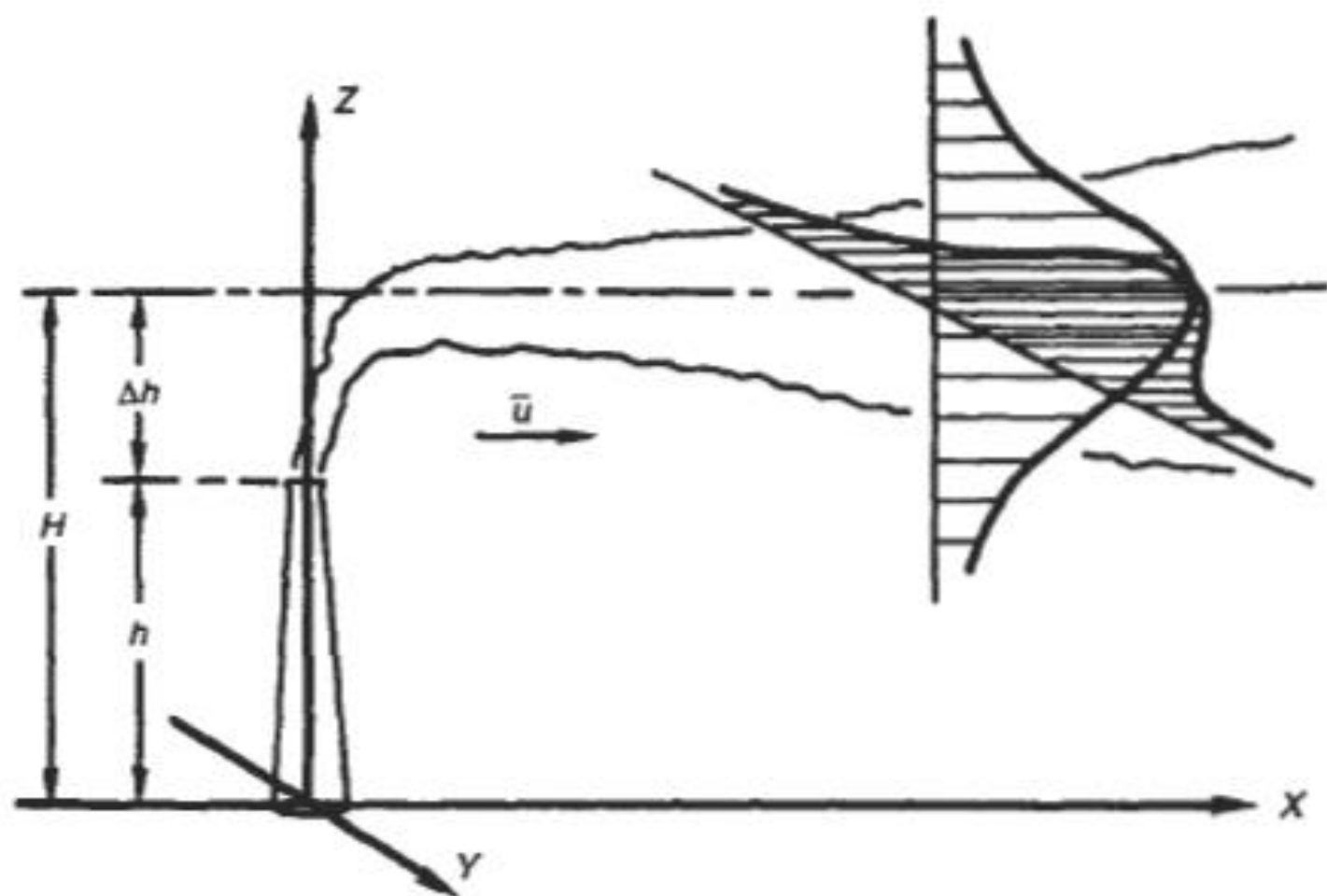
Dispersion is the process by which contaminants move through the air and a plume spreads over a large area, thus reducing the concentration of the pollutants it contains.

The plume spreads both horizontally and vertically. If it is a gaseous plume, the motion of the molecules follows the laws of gaseous diffusion.

The principles on which the model is based

- 1. The predominant force in pollution transport is the wind; pollutants move predominantly downwind.**
- 2. *The greatest concentration of pollutant molecules is along the plume center line.***
- 3. *Molecules diffuse spontaneously from regions of higher concentration to regions of lower concentration.***
- 4. *The pollutant is emitted continuously, and the emission and dispersion process is steady state.***

$$z = H,$$



$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left(\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) \right), \quad (18.2)$$

where

$C(x, y, z)$ is the concentration at some point in space with coordinates x, y, z , and

Q = the emission rate of the pollution source (in g/s),

u = the average wind speed in (m/s),

σ_y = the standard deviation of the plume in the y direction (m), and

σ_z = the standard deviation of the plume in the z direction (m).

$$C(x, y, 0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left(\exp\left(-\frac{(H)^2}{2\sigma_z^2}\right) \right).$$

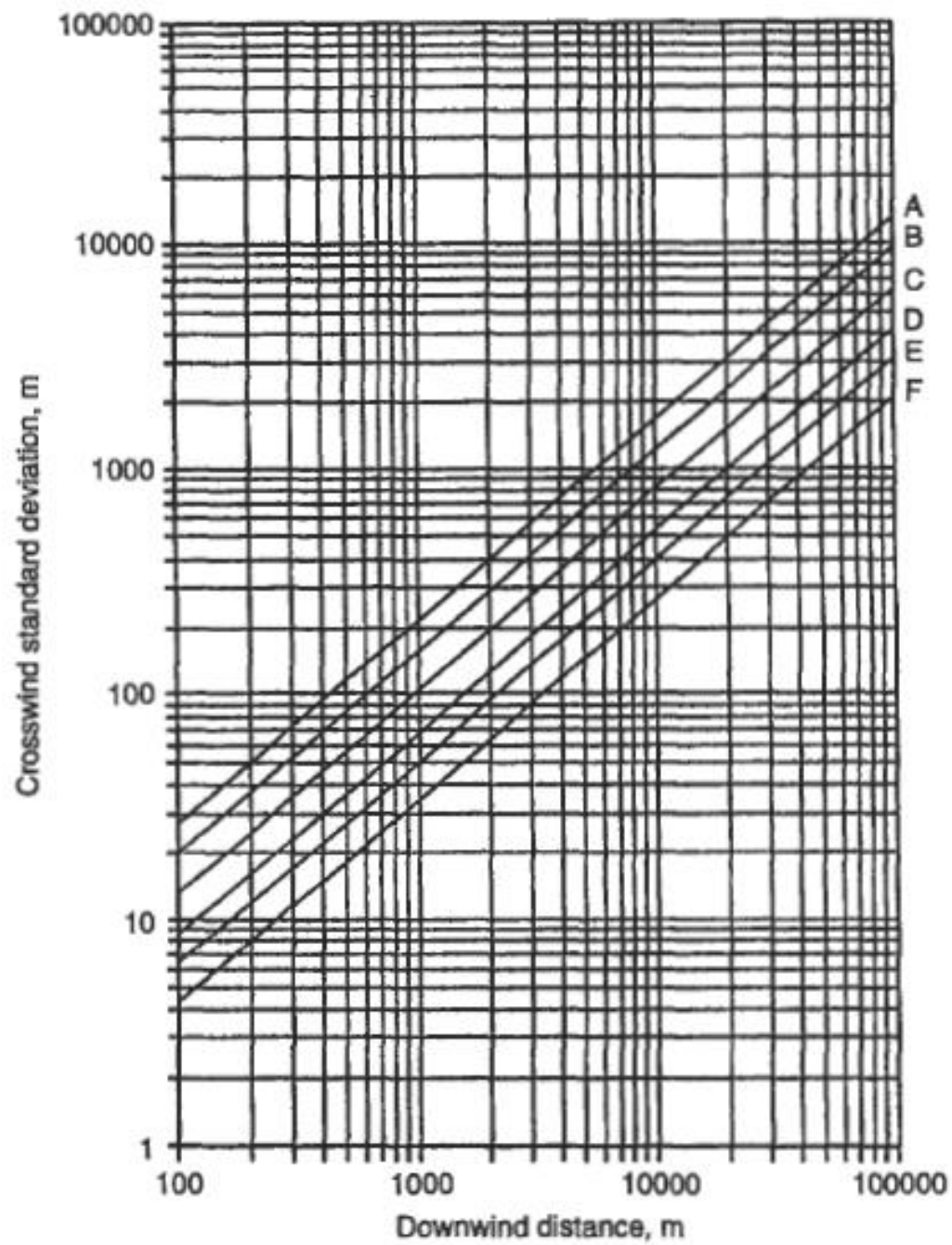
$$C(x, 0, 0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(\frac{-H^2}{2\sigma_z^2}\right).$$

Finally, for a source of emission at ground level, $H = 0$, and the ground level concentration of pollutant downwind along the plume centerline is given by

$$C(x, 0, 0) = \frac{Q}{\pi u \sigma_y \sigma_z}.$$

For a release above ground level the maximum downwind ground level concentration occurs along the plume centerline when the following condition is satisfied

$$\sigma_z = \frac{H}{\sqrt{2}}$$



σ_y

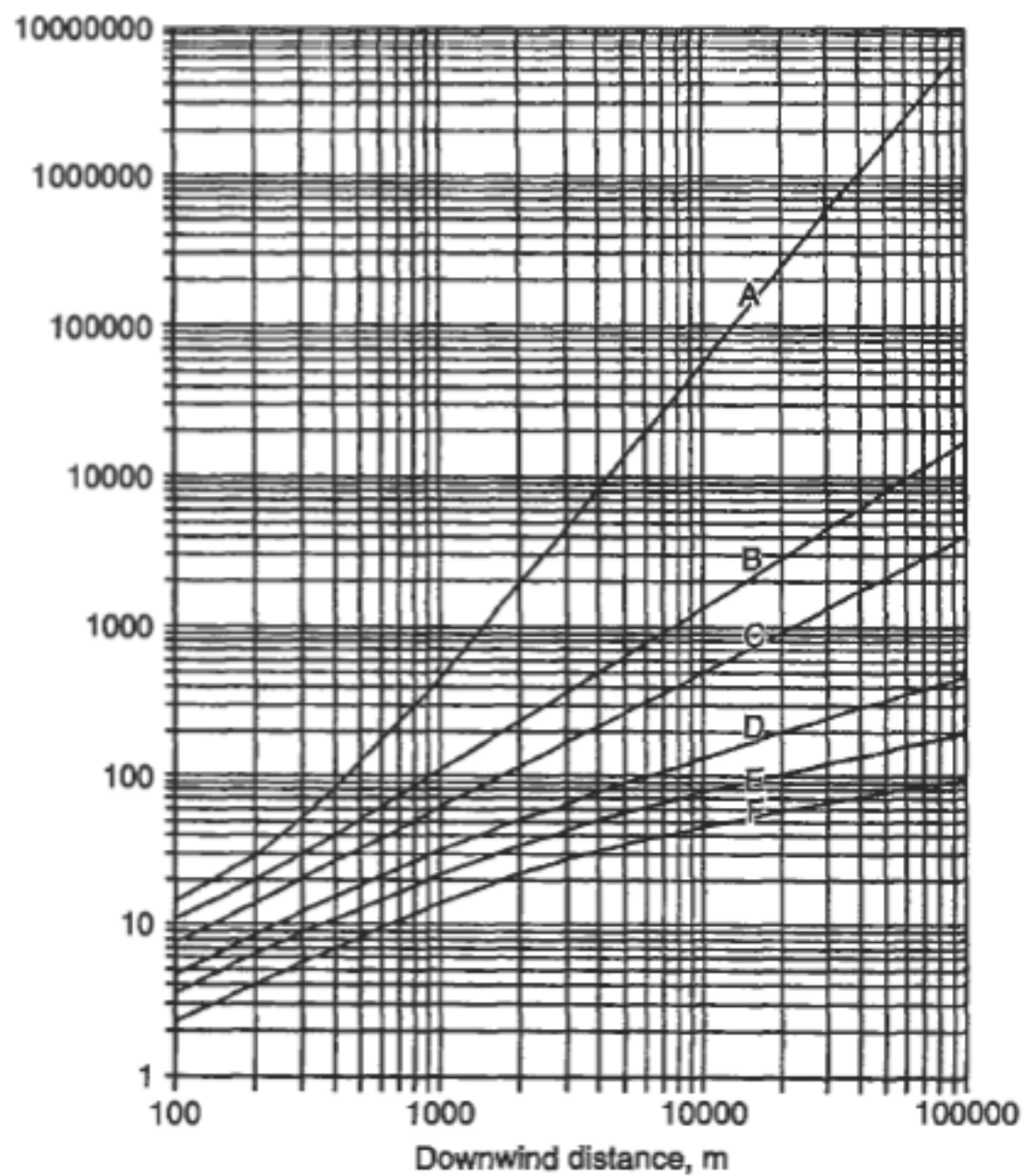


Table 18-1. Atmospheric Stability under Various Conditions

Wind speed at 10 m (m/s)	Day			Night	
	Incoming solar radiation			Thin overcast	
	Strong	Moderate	Slight	1/2 low cloud	3/8 cloud
<2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	E
>6	C	D	D	D	D

EXAMPLE 18.2. An oil pipeline leak results in emission of 100 g/h of H_2S . On a very sunny summer day, with a wind speed of 3.0 m/s, what will be the concentration of H_2S 1.5 km directly downwind from the leak?

From Table 18-1, we may assume Class B stability. Then, from Fig. 18-16, at $x = 1.5$ km, σ_y is approximately 210 m and, from Fig. 18-17, σ_z is approximately 160 m, and

$$Q = 100 \text{ g/h} = 0.0278 \text{ g/s}.$$

Applying Eq. (18.5), we have

$$C(1500, 0, 0) = \frac{0.0278 \text{ g/s}}{\pi(3.0 \text{ m/s})(210 \text{ m})(160 \text{ m})} = 8.77 \times 10^{-8} \text{ g/m}^3 = 0.088 \mu\text{g/m}^3.$$

EXAMPLE 18.3. A coal-burning electric generating plant emits 1.1 kg/min of SO₂ from a stack with an effective height of 60 m. On a thinly overcast evening, with a wind speed of 5.0 m/s, what will be the ground level concentration of SO₂ 500 m directly downwind from the stack?

From Table 18-1, we may assume Class D stability. Then, from Fig. 18-16, at $x = 0.5$ km, σ_y is approximately 35 m and σ_z is approximately 19 m, and

$$Q = 1.1 \text{ kg/min} = 18 \text{ g/s.}$$

In this problem, the release is elevated, and $H = 60$ m.

Applying Eq. (18.4), we have

$$C(0.5, 0, 0) = \frac{18 \text{ g/s}}{\pi (5 \text{ m/s})(35 \text{ m})(19 \text{ m})} \exp \left(\frac{-(60)^2}{2(19)^2} \right) = 11.8 \times 10^{-6} \text{ g/m}^3,$$

or $11.8 \mu\text{g/m}^3$.

Variation of Wind Speed With Elevation

$$u = u_0 \left(\frac{h}{h_0} \right)^n$$

Table 18-2. Relationship between the Stability Parameter and Atmospheric Stability^a

Stability condition	<i>n</i>
Large lapse rate (Classes A, B, C)	0.20
Zero or small lapse rate (Class D)	0.25
Moderate inversion (Class E)	0.33
Strong inversion (Classes F and G)	0.50

Effective Stack Height

superadiabatic conditions $\Delta h = 3.47 \frac{V_s d}{u} + 5.15 \frac{Q_h^{0.5}}{u};$

neutral stability $\Delta h = 0.35 \frac{V_s d}{u} + 2.64 \frac{Q_h^{0.5}}{u}$

subadiabatic conditions $\Delta h = -1.04 \frac{V_s d}{u} + 2.24 \frac{Q_h^{0.5}}{u},$

where

V_s = stack gas exit speed (in m/s),

d = stack diameter (in m), and

Q_h = heat emission rate from the stack (in kJ/s).

EXAMPLE 18.4. A power plant has a stack with a diameter of 2 m and emits gases with a stack exit velocity of 15 m/s and a heat emission rate of 4,800 kJ/s. The wind speed is 5 m/s. Stability is neutral. Estimate the plume rise. If the stack has a geometric height of 40 m, what is the effective stack height?

Using Eq. (18.8b),

$$\Delta h = 0.35 \frac{(15)(2)}{5} + 2.64 \frac{\sqrt{4800}}{5} = 38.7 \text{ m}$$

$$H = h_g + h$$

$$H = 40 \text{ m} + 38.7 \text{ m} = 78.7 \text{ m.}$$