

THE NATURE OF ATMOSPHERIC PRESSURES

Definitions

Pressure – Pressure, as a physical phenomenon, is defined as the force exerted over an area. Therefore its dimensions are $MLT^{-2}L^{-2}$. This is sometimes reduced algebraically to $ML^{-1}T^{-2}$. Pressure is measured in newtons per square meter or in Pascals. One newton per square meter is one Pascal.

Gas Pressure – Gas pressures are the pressures that gases exert on surfaces exposed to them. Although on the macroscopic scale gas pressures are thought of as continuous and relatively steady, on the molecular level they may be seen to be both intermittent and highly variable. Gas pressures are essentially a matter of scale—both of area and of time. Hence,

$$\bar{p} = \sum_1^{\bar{f}_i} \phi_i \quad \text{NAP01}$$

Here, \bar{p} is the mean gas pressure in Pascals, \bar{f}_i is the mean number of impacts experienced by a square meter of exposed surface in one second, and ϕ_i is the individual impulse of each impact in newtons.

Areas of surface on the scale of molecular cross-sections thus experience brief periods of time when the pressures upon them can be hundreds of times greater than the mean gas pressure interspersed with periods when there is no pressure at all. It is only our human limitations and the limited sensitivities of our instruments that give us the illusion of gas pressures as a relatively steady and unremitting force.

Atmospheric Pressures – Atmospheric pressures are the pressures that the gases of the atmosphere exert on surfaces exposed to the atmosphere. They may be measured with either a barometer or a manometer. Both devices measure the same thing.

Universal Pressure Equation

Put NAP01 another way and we get the *Universal Pressure Equation*:

$$\bar{p} = \bar{f}_i \bar{\phi}_i \quad \text{NAP02}$$

Here, \bar{p} is the mean pressure per square meter in Pascals, \bar{f}_i is the mean number of molecular impacts per square meter of surface per second, and $\bar{\phi}_i$ is the mean molecular impulse per impact upon that surface in newtons.

Being essentially a definition, this pressure equation is universal. It is valid for ideal gases and for real gases, under conditions of equilibrium and under conditions of non-equilibrium, in the laboratory and in the free atmosphere, for still air and for moving air. It is even valid for moving objects in moving air.

Obviously, given the variety of conditions under which this equation is presumed be valid, we can expect the values of the right-hand terms to change significantly as conditions change. And, indeed, they do. However, it is still possible to keep them universal for a while.

Universal Flux Equation – Let us start with the molecular flux term \bar{f}_i . As we saw in [Molecular Flows](#), this term can be expanded to

$$\bar{f}_i = \bar{n}_p \bar{v}_p \quad \text{NAP03}$$

Here, \bar{f}_i is the mean number of molecular impacts per square meter per second, \bar{n}_p is the mean number of molecules per cubic meter that have a component of movement toward that surface, and \bar{v}_p is the mean velocity of those molecules normal to that surface.

This is also a definition, and this flux equation is also universal. It is valid for ideal gases and for real gases, under conditions of equilibrium and under conditions of non-equilibrium, in the laboratory and in the free atmosphere, for still air and for moving air. It is even valid for the molecular flux upon moving objects in moving air.

As before, however, the devil is in the details. The values of the right-hand terms will be different in still air than in moving air. The flux upon a moving object will be different from the flux on a stationary object. And the flux upon a moving object in moving air will be different yet.

Universal Impulse Equation – As we saw in [Molecular Impulses](#), the impulse transferred during gaseous molecular collisions at temperatures and pressures normally encountered in the free atmosphere is almost entirely translational. There does not appear to be any significant transfer of either rotational or vibrational energies.

As we saw in the [Equipartition Conundrum](#), these energies may indeed be transferred during molecular “collisions”; but this transfer is so infrequent due to quantum considerations as to render it insignificant in terms of the magnitude of the mean impulse.

This finding allows us to expand the mean impulse term $\bar{\phi}_i$. We get,

$$\bar{\phi}_i = \frac{1}{\bar{f}_i} \sum_1^{\bar{f}_i} \phi_i \quad \text{NAP04}$$

Here ϕ_i is the individual molecular impulse at impact. This is essentially the change in momentum that the molecule undergoes during the duration of its impact with the surface. This takes the form,

$$\phi_i = \Delta\rho = \frac{d\rho}{dt} = \int_{\text{initial contact}}^{\text{final contact}} \rho = \rho_i + \rho_{-i} \quad \text{NAP05}$$

Here, ρ is the individual molecular momentum in kilogram-meters per second. If we assume that the molecular impact is elastic, then:

$$\phi_i = 2m_i v_i \quad \text{NAP06}$$

Here m_i is the individual molecular impulse mass in kilograms and v_i is the individual molecular velocity normal to the surface at the instant of impact.

Combining equations NAP03 and NAP06 gives us,

$$\bar{\phi}_i = 2\bar{m}_i \bar{v}_i \quad \text{NAP07}$$

Here, \bar{m}_i is the mean molecular impulse mass and \bar{v}_i is the mean molecular impulse velocity normal to the surface at both initial and terminal impact.

Being once more essentially a definition, this impulse equation is once more universal. It is valid for ideal gases and for real gases, under conditions of equilibrium and under conditions of non-equilibrium, in the laboratory and in the free atmosphere, for still air and for moving air. It is even valid for the mean molecular impulse upon moving objects in moving air.

And still again, the devil is once more in the details. The values of the right-hand terms will be different in still air than in moving air. The impulse upon a moving object will be different from the impulse on a stationary object. And the impulse upon a moving object in moving air will be different yet.

Frequency of Impact in Still Air

In still air, half of the atmospheric gas molecules will have a component of motion toward the exposed surface, and half will be moving away from that surface. Therefore,

$$\bar{n}_p = \frac{1}{2} \bar{n} \quad \text{NAP08}$$

Substituting NAP08 into NAP03 gives us,

$$\bar{f}_i^e = \frac{1}{2} \bar{n} \bar{v}_p \quad \text{NAP09}$$

Here \bar{f}_i^e is the mean molecular flux under conditions of equilibrium, which includes still air.

Combining formulae NAP02, NAP03, and NAP09 gives us:

$$\bar{p} = (\bar{n}_p \bar{v}_p) (2\bar{m}_i \bar{v}_i) = 2\bar{n}_p \bar{m}_i (\bar{v}_i \bar{v}_p) \quad \text{NAP10}$$

Here, all the terms have their previously defined meanings.

As we saw in [*Molecular Speeds and Velocities*](#),

$$\sigma^2 = (\bar{v}_i \bar{v}_p) \quad \text{NAP11}$$

Here, of course, σ^2 is the mean of the squares of the component velocities, or (from a statistical point of view) the variance of the component velocities.

We now have

$$\bar{p} = 2\bar{n}_p \bar{m}_i \sigma^2 \quad \text{NAP12}$$

Here, all the terms also have their previously defined meanings.

This simplifies to,

$$\bar{p} = \bar{n}\bar{m}_i\sigma^2 \quad \text{NAP13}$$

This expression is readily recognized as the statistical mechanical equation of state for a mixture of ideal gases under conditions of equilibrium.

KET20 in [Kinetic Energies of Translation](#) gives us

$$\bar{m}_i\sigma^2 = k_B\bar{T} \quad \text{NAP14}$$

Substitution of NAP14 into NAP13 gives us

$$\bar{p} = \bar{n}k_B\bar{T} \quad \text{NAP15}$$

This expression is readily recognized as the kinetic gas equation of state for an ideal gas under conditions of equilibrium.

Although equations NAP13 and NAP15 may properly be applied only to ideal gases, we may—on occasion—apply them to the free atmosphere as long as at least a state of [quasi-equilibrium](#) exists. That is, as long as the wind movement is imperceptible.

Summary – Atmospheric pressures are the pressures that the gases of the atmosphere exert on surfaces exposed to those gases. Although on the macroscopic scale atmospheric pressures are thought of as continuous and relatively steady, on the molecular level they may be seen to be both intermittent and highly variable. Atmospheric pressures are not the result of a continuous force, such as that of gravity, but of a very large collection of very small forces—molecular impulses.

Or, to repeat NAP01,

$$\bar{p} = \sum_1^{\bar{f}_i} \phi_i$$

NAP01

Thus, the measurements of atmospheric pressures that we see as continuous and relatively steady are in reality artifacts of the scales of area and of time that we customarily use in those measurements.

TABLES

In the tables that follow, all calculations were carried out by Microsoft's© Excel Program 2003 (SP3). This program uses fifteen significant figures for all parameters. The values of Boltzmann's Constant (k_B) and mean molecular impulse mass for dry air (\bar{m}_i) are thus carried out to fifteen significant figures.

The reader may argue that this level of precision far exceeds the level of accuracy. I agree, but the program does what the program does. For the sake of replication, the values used by the program are:

$$k_B = 1.380650400000000 \times 10^{-23} \text{ J K}^{-1}$$

$$\bar{m}_i = 4.795045174731700 \times 10^{-26} \text{ kg}$$

Note that the mass given above is not the mean molecular mass of dry air; it is the mean molecular impulse mass of dry air. For the difference between the two and its significance, see [Molecular Masses](#).

The atmospheric pressure used in the following tables has been set at 1000 hectopascals. This value allows for the easiest reader computation of parameter values for other atmospheric pressures. Simple decimal multiplication usually suffices to obtain values for other pressures.

Keep in mind that all values are for stationary surfaces in still air. For other conditions, the reader is referred to more advanced treatments elsewhere in this collection.

Tables for the individual parameters that make up the molecular flow rate may be found in [Molecular Flows](#).

Tables for the individual parameters that make up the mean molecular impulses may be found in [Molecular Impulses](#).

TABLE NAP01A

MOLECULAR FLUX PARAMETERS IN STILL AIR
AT 1000 HECTOPASCALS AND SELECTED TEMPERATURES

SYSTEM TEMP	SYSTEM TEMP	MOLECULES MOVING TOWARD SURFACE	MEAN MOLECULAR PROXIMITY VELOCITY
°C	K	\bar{n}_p	\bar{v}_p
		x 10 ²⁵	
		molecules m ⁻³	m sec ⁻¹
75	348.15	1.0402	252.62
70	343.15	1.0554	250.80
65	338.15	1.0710	248.97
60	333.15	1.0870	247.12
55	328.15	1.1036	245.26
50	323.15	1.1207	243.38
45	318.15	1.1383	241.49
40	313.15	1.1565	239.59
35	308.15	1.1752	237.67
30	303.15	1.1946	235.73
25	298.15	1.2147	233.78
20	293.15	1.2354	231.81
15	288.15	1.2568	229.82
10	283.15	1.2790	227.82
5	278.15	1.3020	225.80
0	273.15	1.3258	223.76

TABLE NAP01B

MOLECULAR FLUX PARAMETERS IN STILL AIR
AT 1000 HECTOPASCALS AND SELECTED TEMPERATURES

SYSTEM TEMP	SYSTEM TEMP	MOLECULES MOVING TOWARD SURFACE	MEAN MOLECULAR PROXIMITY VELOCITY
°C	K	\bar{n}_p	\bar{v}_p
		$\times 10^{25}$	
		molecules m ⁻³	m sec ⁻¹
0	273.15	1.3258	223.76
-5	268.15	1.3505	221.70
-10	263.15	1.3762	219.63
-15	258.15	1.4029	217.53
-20	253.15	1.4306	215.41
-25	248.15	1.4594	213.28
-30	243.15	1.4894	211.12
-35	238.15	1.5207	208.93
-40	233.15	1.5533	206.73
-45	228.15	1.5873	204.50
-50	223.15	1.6229	202.25
-55	218.15	1.6601	199.97
-60	213.15	1.6990	197.66
-65	208.15	1.7398	195.33
-70	203.15	1.7827	192.97
-75	198.15	1.8276	190.58

TABLE NAP02A

MOLECULAR IMPULSE PARAMETERS IN STILL AIR
AT 1000 HECTOPASCALS AND SELECTED TEMPERATURES

SYSTEM TEMP	SYSTEM TEMP	MEAN IMPULSE VELOCITY	MEAN PRESSURE PER IMPACT
°C	K	\bar{v}_i	\bar{p}_i
		m sec ⁻¹	hPa m ⁻²
75	348.15	396.82	217359
70	343.15	393.96	214237
65	338.15	391.08	211116
60	333.15	388.17	207994
55	328.15	385.25	204873
50	323.15	382.30	201751
45	318.15	379.33	198629
40	313.15	376.34	195508
35	308.15	373.32	192386
30	303.15	370.28	189264
25	298.15	367.22	186143
20	293.15	364.12	183021
15	288.15	361.01	179900
10	283.15	357.86	176778
5	278.15	354.69	173656
0	273.15	351.48	170535

TABLE NAP02B

MOLECULAR IMPULSE PARAMETERS IN STILL AIR
AT 1000 HECTOPASCALS AND SELECTED TEMPERATURES

SYSTEM TEMP	SYSTEM TEMP	MEAN IMPULSE VELOCITY	MEAN PRESSURE PER IMPACT
°C	K	\bar{v}_i	\bar{p}_i
		m sec ⁻¹	hPa m ⁻²
0	273.15	351.48	170535
-5	268.15	348.25	167413
-10	263.15	344.99	164291
-15	258.15	341.70	161170
-20	253.15	338.37	158048
-25	248.15	335.01	154926
-30	243.15	331.62	151805
-35	238.15	328.19	148683
-40	233.15	324.73	145562
-45	228.15	321.23	142440
-50	223.15	317.69	139318
-55	218.15	314.11	136197
-60	213.15	310.49	133075
-65	208.15	306.83	129953
-70	203.15	303.12	126832
-75	198.15	299.37	123710

TABLE NAP03A

PRESSURE PARAMETERS IN STILL AIR AT 1000 HECTOPASCALS
AND SELECTED TEMPERATURES

SYSTEM TEMP	SYSTEM TEMP	MEAN MOLECULAR FLOW RATE	MEAN MOLECULAR IMPULSE
°C	K	\bar{f}_i	$\bar{\Phi}_i$
		x 10 ²⁷	x 10 ⁻²³
		impacts m ⁻² sec ⁻¹	newtons
75	348.15	2.62778	3.8055
70	343.15	2.64685	3.7781
65	338.15	2.66635	3.7504
60	333.15	2.68628	3.7226
55	328.15	2.70667	3.6946
50	323.15	2.72753	3.6663
45	318.15	2.74888	3.6378
40	313.15	2.77074	3.6091
35	308.15	2.79313	3.5802
30	303.15	2.81607	3.5511
25	298.15	2.83958	3.5216
20	293.15	2.86370	3.4920
15	288.15	2.88843	3.4621
10	283.15	2.91383	3.4319
5	278.15	2.93990	3.4015
0	273.15	2.96668	3.3708

TABLE NAP03B

PRESSURE PARAMETERS IN STILL AIR AT 1000 HECTOPASCALS
AND SELECTED TEMPERATURES

SYSTEM TEMP	SYSTEM TEMP	MEAN MOLECULAR FLOW RATE	MEAN MOLECULAR IMPULSE
°C	K	\bar{f}_i	$\bar{\Phi}_i$
		x 10 ²⁷	x 10 ⁻²³
		impacts m ⁻² sec ⁻¹	newtons
0	273.15	2.96668	3.3708
-5	268.15	2.99421	3.3398
-10	263.15	3.02253	3.3085
-15	258.15	3.05166	3.2769
-20	253.15	3.08165	3.2450
-25	248.15	3.11254	3.2128
-30	243.15	3.14438	3.1803
-35	238.15	3.17721	3.1474
-40	233.15	3.21110	3.1142
-45	228.15	3.24610	3.0806
-50	223.15	3.28226	3.0467
-55	218.15	3.31966	3.0124
-60	213.15	3.35837	2.9776
-65	208.15	3.39847	2.9425
-70	203.15	3.44004	2.9069
-75	198.15	3.48317	2.8709

REFERENCES

INTERNAL REFERENCES: These are other papers in this collection that are either cited or linked during the course of the discussion or whose content is especially relevant to the current discussion.

Molecular Numbers – This paper defines the number density parameters ($\bar{n}, \bar{n}_p, \bar{n}_i$) and shows how they derive from Avogadro's Law.

Molecular Masses – This paper defines the molecular mass parameters (\bar{m}, \bar{m}_i) and shows how their values were calculated.

Molecular Speeds and Velocities – This absolutely essential paper defines the various velocity terms ($\sigma, \bar{v}_p, \bar{v}_i$) used throughout this collection of papers and shows how they are derived and how they relate to one another mathematically.

Molecular Flows – This paper defines the flow parameter (\bar{f}_i) and shows how it is derived. The concept of a Universal Flux Equation is introduced.

Kinetic Energies of Translation – This paper is a fundamental paper in this collection. It defines the various molecular kinetic energies of translation ($\bar{u}, \bar{u}_\sigma, \bar{u}_p, \bar{u}_i, \bar{u}_i'$) and shows how each is derived. It goes on to show the mathematical relationships between the various energies and their relation to the thermal term ($k_B \bar{T}$).

The Probability Density Curve – This paper discusses the significance and history of the probability density curve. It goes on to show how in its normalized form it is also the distribution function for axial velocities.

The Equipartition Conundrum – This paper discusses the equipartition conundrum; that is, why molecular collisions appear to transfer only kinetic energies of translation and not kinetic energies of either rotation or vibration.

EXTERNAL REFERENCES: These are papers by other authors that contain statements or data that are specifically incorporated into the current discussion.

D. Tabor; **Gases, Liquids, and Solids**; Third Edition; Cambridge University Press, 1991.

Arthur Brown; **Statistical Physics**; Elsevier, New York, 1970.

James Jeans; **An Introduction to the Kinetic Theory of Gases**; Cambridge Library Collection, 1940.