Appendix A: Pressure Conversions

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Pressure Units** | | | | | | |
|  | [**Pascal**](http://en.wikipedia.org/wiki/Pascal_%28unit%29) **(Pa)** | [**Bar**](http://en.wikipedia.org/wiki/Bar_%28unit%29) **(bar)** | [**Technical atmosphere**](http://en.wikipedia.org/wiki/Technical_atmosphere) **(at)** | [**Atmosphere**](http://en.wikipedia.org/wiki/Atmosphere_%28unit%29) **(atm)** | [**Torr**](http://en.wikipedia.org/wiki/Torr) **(mmHg)** | [**Pound-force per square inch**](http://en.wikipedia.org/wiki/Pound-force_per_square_inch) **(psi)** |
| **1 Pa** | ≡ 1 N/m² | 10−5 | 10.197×10−6 | 9.8692×10−6 | 7.5006×10−3 | 145.04×10−6 |
| **1 bar** | 100 000 | ≡ 106 dyn/cm² | 1.0197 | 0.98692 | 750.06 | 14.504 |
| **1 at** | 98 066.5 | 0.980665 | ≡ 1 kgf/cm² | 0.96784 | 735.56 | 14.223 |
| **1 atm** | 101 325 | 1.01325 | 1.0332 | ≡ 1 [atm](http://en.wikipedia.org/wiki/Atmosphere_%28unit%29) | 760 | 14.696 |
| **1 torr** | 133.322 | 1.3332×10−3 | 1.3595×10−3 | 1.3158×10−3 | ≡ 1 mmHg | 19.337×10−3 |
| **1 psi** | 6 894.76 | 68.948×10−3 | 70.307×10−3 | 68.046×10−3 | 51.715 | ≡ 1 lbf/in² |

**Example reading:** 1 Pa = 1 N/m² = 10−5 bar = 10.197×10−6 at = 9.8692×10−6 atm ....etc.

## Altitude atmospheric pressure variation

|  |  |  |
| --- | --- | --- |
| **fraction of 1 atm** | **average altitude** | |
| **(m)** | **(ft)** |
| 1 | 0 | 0 |
| 1/2 | 5,486.3 | 18,000 |
| 1/3 | 8,375.8 | 27,480 |
| 1/10 | 16,131.9 | 52,926 |
| 1/100 | 30,900.9 | 101,381 |
| 1/1000 | 48,467.2 | 159,013 |
| 1/10000 | 69,463.6 | 227,899 |
| 1/100000 | 96,281.6 | 283,076 |

## 

## Calculating variation with altitude

Equation 1:

{P}=P_b \cdot \left[\frac{T_b}{T_b + L_b\cdot(h-h_b)}\right]^\frac{g_0 \cdot M}{R^* \cdot L_b}

Equation 2:

{P}=P_b \cdot \exp \left[\frac{-g_0 \cdot M \cdot (h-h_b)}{R^* \cdot T_b}\right]

where

*P* = Static pressure (pascals)

*T* = Standard temperature (kelvins)

*L* = Standard temperature lapse rate (kelvins per meter)

*h* = Height above sea level (meters)

*R* \* = Universal gas constant for air: 8.31432×103 N·m / (kmol·K)

*g*0 = Gravitational constant (9.80665 m/s²)

*M* = Molar mass of Earth's air (28.9644 g/mol)

Or converted to English units:

where

*P* = Static pressure (inches of mercury)

*T* = Standard temperature (kelvins)

*L* = Standard temperature lapse rate (kelvins per foot)

*h* = Height above sea level (feet)

*R* \* = Universal gas constant (using feet and kelvins and gram moles: 8.9494596×104 kg·ft2·s-2·K-1·kmol-1)

*g*0 = Gravitational constant (32.17405 ft/s²)

*M* = Molar mass of Earth's air (28.9644 g/mol)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Subscript *b*** | **Height Above Sea Level** | | **Static Pressure** | | **Standard Temperature (K)** | **Temperature Lapse Rate** | |
| **(m)** | **(ft)** | **(pascals)** | **(inHg)** | **(K/m)** | **(K/ft)** |
| 0 | 0 | 0 | 101325 | 29.92126 | 288.15 | -0.0065 | -0.0019812 |
| 1 | 11,000 | 36,089 | 22632.1 | 6.683245 | 216.65 | 0.0 | 0.0 |
| 2 | 20,000 | 65,617 | 5474.89 | 1.616734 | 216.65 | 0.001 | 0.0003048 |
| 3 | 32,000 | 104,987 | 868.019 | 0.2563258 | 228.65 | 0.0028 | 0.00085344 |
| 4 | 47,000 | 154,199 | 110.906 | 0.0327506 | 270.65 | 0.0 | 0.0 |
| 5 | 51,000 | 167,323 | 66.9389 | 0.01976704 | 270.65 | -0.0028 | -0.00085344 |
| 6 | 71,000 | 232,940 | 3.95642 | 0.00116833 | 214.65 | -0.002 | -0.0006096 |

Sample Calculation:

Find the pressure at 30,000 meters. First note that 30,000 meters is above 20,000 but below 32,000 so it therefore falls in the range of subscript b=2 in the chart above. Also note that the temperature lapse rate for that region is not equal to zero; therefore, equation 1 is appropriate.

{P}=P_2 \cdot \left[\frac{T_2}{T_2 + L_2\cdot(h-h_2)}\right]^\frac{g_0 \cdot M}{R^* \cdot L_2}

Or

{P}=5474.89 \cdot \left[\frac{216.65}{216.65 + 0.001\cdot(30,000-20,000)}\right]^\frac{9.80665  \cdot 28.9644}{8314.32 \cdot 0.001}

{P}=5474.89 \cdot \left[\frac{216.65}{226.65)}\right]^{34.163195}

{P}=5474.89 \cdot 0.214044

{P}\ = 1171.867 (Pascals at 30,000 meters)

**Conversion Table for Pressure**

|  |  |  |
| --- | --- | --- |
| **To convert** | **Into** | **Multiply by** |
| atmosphere | bar | 1.01295 |
| atmosphere | dynes/cm2 | 1.01295 x 106 |
| atmosphere | in. Hg | 29.9213 |
| atmosphere | in. water | 406.86 |
| atmosphere | kg/cm2 | 1.03325 |
| atmosphere | mbar | 1012.95 |
| atmosphere | mtorr or micron Hg | 7.6 x 105 |
| atmosphere | Pa or N/m2 | 1.01295 x 105 |
| atmosphere | PSI or lb/in2 | 14.696 |
| atmosphere | torr or mm Hg | 760 |
| bar | atmosphere | 0.9872 |
| bar | dynes/cm2 | 1 x 106 |
| bar | in. Hg | 29.54 |
| bar | in. water | 401.65 |
| bar | kg/cm2 | 1.02 |
| bar | mbar | 1000 |
| bar | mtorr or micron Hg | 7.5028 x 105 |
| bar | Pa or N/m2 | 1 x 105 |
| bar | psi or lb/in2 | 14.503861 |
| bar | torr or mm Hg | 750.2838 |
| dynes/cm2 | atmosphere | 9.872 x 10-7 |
| dynes/cm2 | bar | 1 x 10-6 |
| dynes/cm2 | in. Hg | 2.954 x 10-5 |
| dynes/cm2 | in. water | 4.0165 x 10-4 |
| dynes/cm2 | kg/cm2 | 1.0200 x 10-6 |
| dynes/cm2 | mbar | 1 x 10-3 |
| dynes/cm2 | mtorr or micron Hg | 0.75028 |
| dynes/cm2 | Pa or N/m2 | 0.1 |
| dynes/cm2 | psi or lb/in2 | 1.4508 x 10-5 |
| dynes/cm2 | torr or mm Hg | 7.5028 x 10-4 |
| in. Hg | atmosphere | 3.342 x 10-2 |
| in. Hg | bar | 3.385 x 10-2 |
| in. Hg | dynes/cm2 | 3.385 x 104 |
| in. Hg | in. water | 13.598 |
| in. Hg | kg/cm2 | 3.4532 x 10-2 |
| in. Hg | mbar | 33.85 |
| in. Hg | mtorr or micron Hg | 2.54 x 104 |
| in. Hg | Pa or N/m2 | 3385 |
| in. Hg | psi or lb/in2 | 0.4912 |
| in. Hg | torr or mm Hg | 25.4 |
| in. water | atmosphere | 2.458 x 10-3 |
| in. water | bar | 2.489 x 10-3 |
| in. water | dynes/cm2 | 2.489 x 103 |
| in. water | kg/cm2 | 2.5396 x 10-3 |
| in. water | in. Hg | 7.354 x 10-2 |
| in. water | mbar | 2.489 |
| in. water | mtorr or micron Hg | 1.868 x 10-3 |
| in. water | Pa or N/m2 | 248.9 |
| in. water | psi or lb/in2 | 3.612 x 10-2 |
| in. water | torr or mm Hg | 1.868 |
| kg/cm2 | atmosphere | 0.9678 |
| kg/cm2 | bar | 0.9804 |
| kg/cm2 | dynes/cm2 | 9.804 x 105 |
| kg/cm2 | in. Hg | 28.958 |
| kg/cm2 | in. water | 393.76 |
| kg/cm2 | mbar | 9.804 x 102 |
| kg/cm2 | mtorr or micron Hg | 7.3554 x 105 |
| kg/cm2 | Pa or N/m2 | 9.804 x 104 |
| kg/cm2 | psi or lb/in2 | 14.223 |
| kg/cm2 | torr or mm Hg | 7.3554 x 102 |
| mbar | atmosphere | 9.872 x 10-4 |
| mbar | bar | 0.001 |
| mbar | dynes/cm2 | 1000 |
| mbar | kg/cm2 | 1.0200 x 10-3 |
| mbar | in. Hg | 2.954 x 10-2 |
| mbar | in. water | 0.4018 |
| mbar | mtorr or micron Hg | 7.5028 x 102 |
| mbar | Pa or N/m2 | 100 |
| mbar | psi or lb/in2 | 1.450 x 10-2 |
| mbar | torr or mm Hg | 0.75028 |
| mtorr or micron Hg | atmosphere | 1.316 x 10-6 |
| mtorr or micron Hg | bar | 1.3328 x 10-6 |
| mtorr or micron Hg | dynes/cm2 | 1.3328 |
| mtorr or micron Hg | kg/cm2 | 1.3595 x 10-6 |
| mtorr or micron Hg | in. Hg | 3.937 x 10-5 |
| mtorr or micron Hg | in. water | 5.353 x 10-4 |
| mtorr or micron Hg | mbar | 1.3328 x 10-3 |
| mtorr or micron Hg | Pa or N/m2 | 0.13328 |
| mtorr or micron Hg | psi or lb/in2 | 1.934 x 10-5 |
| mtorr or micron Hg | torr or mm Hg | 1 x 10-3 |
| Pa or N/m2 | atmosphere | 9.869 x 10-6 |
| Pa or N/m2 | bar | 1 x 10-5 |
| Pa or N/m2 | dynes/cm2 | 10 |
| Pa or N/m2 | kg/cm2 | 1.020 x 10-5 |
| Pa or N/m2 | in. Hg | 2.954 x 10-4 |
| Pa or N/m2 | in. water | 4.018 x 10-3 |
| Pa or N/m2 | mbar | 0.01 |
| Pa or N/m2 | mtorr or micron Hg | 7.5028 |
| Pa or N/m2 | psi or lb/in2 | 1.4508 x 10-4 |
| Pa or N/m2 | torr or mm Hg | 7.5028 x 10-3 |
| psi or lb/in2 | atmosphere | 0.068046 |
| psi or lb/in2 | bar | 0.068948 |
| psi or lb/in2 | dynes/cm2 | 6.8948 x 104 |
| psi or lb/in2 | kg/cm2 | 7.0309 x 10-2 |
| psi or lb/in2 | in. Hg | 2.036 |
| psi or lb/in2 | in. water | 27.68 |
| psi or lb/in2 | mbar | 68.948 |
| psi or lb/in2 | mtorr or micron Hg | 5.171 x 104 |
| psi or lb/in2 | Pa or N/m2 | 6.8927 x 103 |
| psi or lb/in2 | torr or mm Hg | 51.71 |
| torr or mm Hg | atmosphere | 1.3158 x 10-3 |
| torr or mm Hg | bar | 1.3328 x 10-3 |
| torr or mm Hg | dynes/cm2 | 1.3328 x 103 |
| torr or mm Hg | kg/cm2 | 1.3595 x 10-3 |
| torr or mm Hg | in. Hg | 3.937 x 10-2 |
| torr or mm Hg | in. water | 0.5353 |
| torr or mm Hg | mbar | 1.3328 |
| torr or mm Hg | mtorr or micron Hg | 1000 |
| torr or mm Hg | Pa or N/m2 | 133.28 |
| torr or mm Hg | psi or lb/in2 | 1.934 x 10-2 |

Appendix B: Cost Analysis

|  |  |  |  |
| --- | --- | --- | --- |
| Option #1: Fix Kinney KC-2 High Vacuum Pump With Factory Parts | | | |
|  |  |  |  |
| Part | Quantity | Price Per | Total Cost |
| Vacuum Torr Gauge | 2 | $399 | $798 |
| Oil Mist Eliminator | 1 | $300 | $300 |
| Oil Mist Eliminator Element | 1 | $80 | $80 |
| Oil Mist Eliminator Gasket | 1 | $4 | $4 |
| Steel Wire Reinforced | 2 | $3.50 | $7.00 |
| High Vacuum Threaded Nipple | 1 | $6.97 | $6.97 |
| Worm-Drive Hose Clamp | 1 | $5 | $5 |
| Flared Fitting to Barbed | 1 | $12.58 | $12.58 |
| Flared to Threaded Joint | 1 | $2.83 | $4.91 |
| Kinney Type AX Oil | 3 Quarts | $10 | $30 |
| Total |  |  | $1,248.46 |

|  |  |  |  |
| --- | --- | --- | --- |
| Option #2: Fix Kinney KC-2 High Vacuum Pump With Various Cheaper Parts | | | |
|  |  |  |  |
| Part | Quantity | Price Per | Total Cost |
| Oil Mist Eliminator From Ebay | 1 | $35 | $35 |
| Supco Digital Vacuum Gauge | 1 | $165.79 | $165.79 |
| Steel Wire Reinforced Vacuum Hose | 2 | $3.50 | $7.00 |
| High Vacuum Threaded Nipple | 1 | $6.97 | $6.97 |
| Worm-Drive Hose Clamp | 1 | $5 | $5 |
| Flared Fitting to Barbed Nipple | 1 | $2.83 | $4.92 |
| Flared to Threaded Joint | 1 | $10 | $10 |
| Kinney Type AX Oil | 3 Quarts | $10 | $30.00 |
| Total |  |  | $264.68 |

|  |  |  |  |
| --- | --- | --- | --- |
| Option #3: Buy Robinair 6 CFM 2 Stage Vacuum Pump | | | |
|  |  |  |  |
| Part | Quantity | Price Per | Total Cost |
| Robinair 6 CFM 2 Stage Vacuum Pump | 1 | $300 | $300 |
| Steel Wire Reinforced Vacuum Hose | 2 | $3.50 | $7.00 |
| High Vacuum Threaded Nipple | 1 | $6.97 | $6.97 |
| Worm-Drive Hose Clamp | 1 | $5 | $5 |
| Flared Fitting to Barbed Nipple | 1 | $12.58 | $12.58 |
| Flared to Threaded Joint | 1 | $2.83 | $4.91 |
| Total |  |  | $336.46 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Pump Specifications | |  |  |  |
|  |  |  |  |  |
| Option | Pump Name | Price | Vacuum | Speed |
| 1 | Kinney KC-2 High Vacuum Pump | $1,223.27 | .1-2 umHg | 2 CFM |
| 2 | Kinney KC-2 High Vacuum Pump | $242.06 | .1-2 umHg | 2 CFM |
| 3 | Robinair 6 CFM 2 Stage Vacuum Pump | $311.27 | 20 umHg | 6 CFM |