# Appendices

# APPENDIX A

# Unit Conversion Tables[1]

The following tables express the definitions of miscellaneous units of measure as exact numerical multiples of coherent SI units and provide multiplying factors for converting numbers and miscellaneous units to corresponding new numbers and SI units.

Conversion factors are expressed using computer exponential notation, and an asterisk follows each number which expresses an exact definition. For example, the entry "2.54 E − 2*" expresses the fact that 1 inch = $2.54 \times 10^{-2}$ meter, exactly by definition. Numbers not followed by an asterisk are only approximate representations of definitions or are the results of physical measurements. In these tables pound-force is designated as lbf, whereas in the text pound-force is designated as lb.

**TABLE A.1**
**Listing by Physical Quantity**

| To convert from | to | Multiply by |
|---|---|---|
| ***Acceleration*** | | |
| foot/second$^2$ | meter/second$^2$ | 3.048 E − 1* |
| free fall, standard | meter/second$^2$ | 9.806 65 E + 0* |
| gal (galileo) | meter/second$^2$ | 1.00 E − 2* |
| inch/second$^2$ | meter/second$^2$ | 2.54 E − 2* |
| ***Area*** | | |
| acre | meter$^2$ | 4.046 856 422 4 E + 3* |
| are | meter$^2$ | 1.00 E + 2* |
| barn | meter$^2$ | 1.00 E − 28* |
| foot$^2$ | meter$^2$ | 9.290 304 E − 2* |

[1]These Tables abridged from Mechtly, E. A., *The International System of Units*, *2nd Revision*, NASA SP-7012, 1973.

■ **TABLE A.1 (continued)**

| To convert from | to | Multiply by |
|---|---|---|
| hectare | meter$^2$ | 1.00 E + 4* |
| inch$^2$ | meter$^2$ | 6.4516 E − 4* |
| mile$^2$ (U.S. statute) | meter$^2$ | 2.589 988 110 336 E + 6* |
| section | meter$^2$ | 2.589 988 110 336 E + 6* |
| township | meter$^2$ | 9.323 957 2 E + 7 |
| yard$^2$ | meter$^2$ | 8.361 273 6 E − 1* |
| ***Density*** | | |
| gram/centimeter$^3$ | kilogram/meter$^3$ | 1.00 E + 3* |
| lbm/inch$^3$ | kilogram/meter$^3$ | 2.767 990 5 E + 4 |
| lbm/foot$^3$ | kilogram/meter$^3$ | 1.601 846 3 E + 1 |
| slug/foot$^3$ | kilogram/meter$^3$ | 5.153 79 E + 2 |
| ***Energy*** | | |
| British thermal unit: (IST after 1956) | joule | 1.055 056 E + 3 |
| British thermal unit (thermochemical) | joule | 1.054 350 E + 3 |
| calorie (International Steam Table) | joule | 4.1868 E + 0 |
| calorie (thermochemical) | joule | 4.184 E + 0* |
| calorie (kilogram, International Steam Table) | joule | 4.1868 E + 3 |
| calorie (kilogram, thermochemical) | joule | 4.184 E + 3* |
| electron volt | joule | 1.602 191 7 E − 19 |
| erg | joule | 1.00 E − 7* |
| foot lbf | joule | 1.355 817 9 E + 0 |
| foot poundal | joule | 4.214 011 0 E − 2 |
| joule (international of 1948) | joule | 1.000 165 E + 0 |
| kilocalorie (Internation Steam Table) | joule | 4.1868 E + 3 |
| kilocalorie (thermochemical) | joule | 4.184 E + 3* |
| kilowatt hour | joule | 3.60 E + 6* |
| watt hour | joule | 3.60 E + 3* |
| ***Force*** | | |
| dyne | newton | 1.00 E − 5* |
| kilogram force (kgf) | newton | 9.806 65 E + 0* |
| kilopound force | newton | 9.806 65 E + 0* |
| kip | newton | 4.448 221 615 260 5 E + 3* |
| lbf (pound force, avoirdupois) | newton | 4.448 221 615 260 5 E + 0* |
| ounce force (avoirdupois) | newton | 2.780 138 5 E − 1 |
| pound force, lbf (avoirdupois) | newton | 4.448 221 615 260 5 E + 0* |
| poundal | newton | 1.382 549 543 76 E − 1* |
| ***Length*** | | |
| angstrom | meter | 1.00 E − 10* |
| astronomical unit (IAU) | meter | 1.496 00 E + 11 |
| cubit | meter | 4.572 E − 1* |
| fathom | meter | 1.8288 E + 0* |
| foot | meter | 3.048 E − 1* |
| furlong | meter | 2.011 68 E + 2* |
| hand | meter | 1.016 E − 1* |
| inch | meter | 2.54 E − 2* |
| league (international nautical) | meter | 5.556 E + 3* |
| light year | meter | 9.460 55 E + 15 |

■ **TABLE A.1 (continued)**

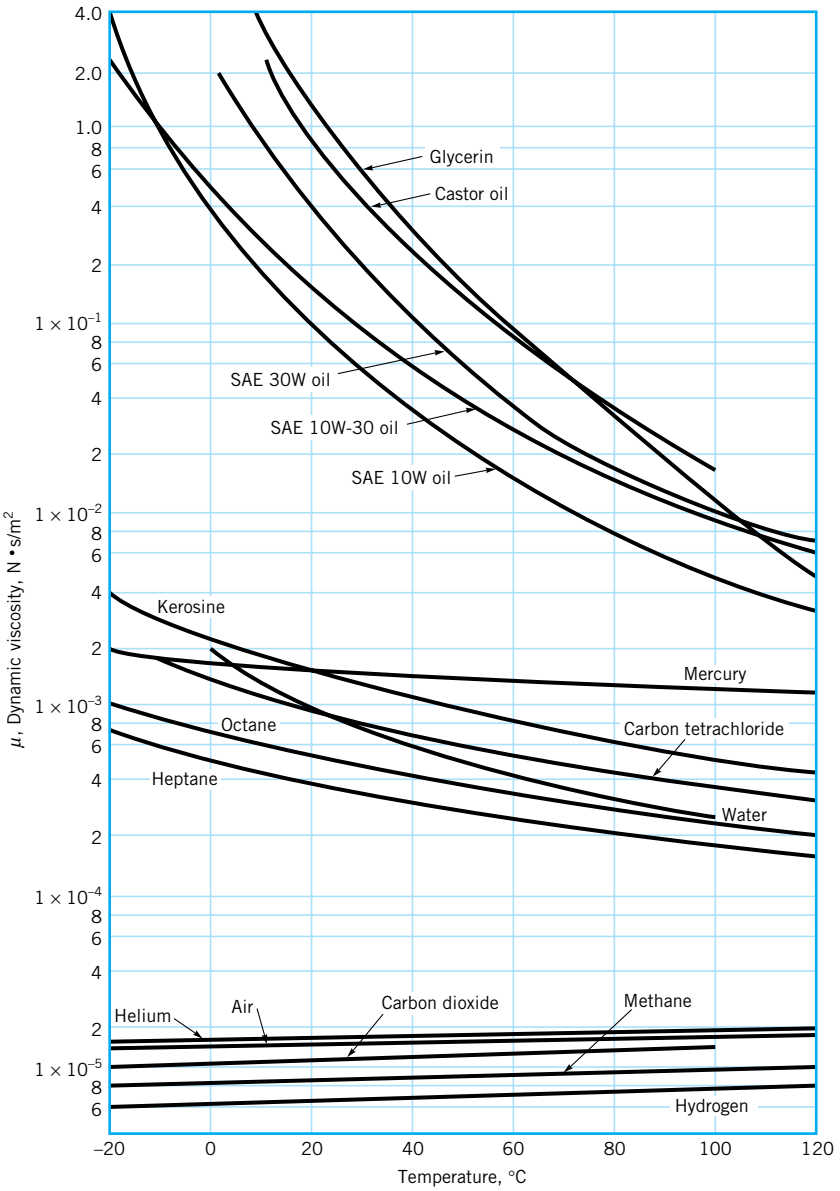
| To convert from | to | Multiply by |
|---|---|---|
| meter | wavelengths Kr 86 | 1.650 763 73 E + 6* |
| micron | meter | 1.00 E − 6* |
| mil | meter | 2.54 E − 5* |
| mile (U.S. statute) | meter | 1.609 344 E + 3* |
| nautical mile (U.S.) | meter | 1.852 E + 3* |
| rod | meter | 5.0292 E + 0* |
| yard | meter | 9.144 E − 1* |
| ***Mass*** | | |
| carat (metric) | kilogram | 2.00 E − 4* |
| grain | kilogram | 6.479 891 E − 5* |
| gram | kilogram | 1.00 E − 3* |
| ounce mass (avoirdupois) | kilogram | 2.834 952 312 5 E − 2* |
| pound mass, lbm (avoirdupois) | kilogram | 4.535 923 7 E − 1* |
| slug | kilogram | 1.459 390 29 E + 1 |
| ton (long) | kilogram | 1.016 046 908 8 E + 3* |
| ton (metric) | kilogram | 1.00 E + 3* |
| ton (short, 2000 pound) | kilogram | 9.071 847 4 E + 2* |
| tonne | kilogram | 1.00 E + 3* |
| ***Power*** | | |
| Btu (thermochemical)/second | watt | 1.054 350 264 488 E + 3 |
| calorie (thermochemical)/second | watt | 4.184 E + 0* |
| foot lbf/second | watt | 1.355 817 9 E + 0 |
| horsepower (550 foot lbf/second) | watt | 7.456 998 7 E + 2 |
| kilocalorie (thermochemical)/second | watt | 4.184 E + 3* |
| watt (international of 1948) | watt | 1.000 165 E + 0 |
| ***Pressure*** | | |
| atmosphere | newton/meter$^2$ | 1.013 25 E + 5* |
| bar | newton/meter$^2$ | 1.00 E + 5* |
| barye | newton/meter$^2$ | 1.00 E − 1* |
| centimeter of mercury (0°C) | newton/meter$^2$ | 1.333 22 E + 3 |
| centimeter of water (4°C) | newton/meter$^2$ | 9.806 38 E + 1 |
| dyne/centimeter$^2$ | newton/meter$^2$ | 1.00 E − 1* |
| foot of water (39.2°F) | newton/meter$^2$ | 2.988 98 E + 3 |
| inch of mercury (32°F) | newton/meter$^2$ | 3.386 389 E + 3 |
| inch of mercury (60°F) | newton/meter$^2$ | 3.376 85 E + 3 |
| inch of water (39.2°F) | newton/meter$^2$ | 2.490 82 E + 2 |
| inch of water (60°F) | newton/meter$^2$ | 2.4884 E + 2 |
| kgf/centimeter$^2$ | newton/meter$^2$ | 9.806 65 E + 4* |
| kgf/meter$^2$ | newton/meter$^2$ | 9.806 65 E + 0* |
| lbf/foot$^2$ | newton/meter$^2$ | 4.788 025 8 E + 1 |
| lbf/inch$^2$ (psi) | newton/meter$^2$ | 6.894 757 2 E + 3 |
| millibar | newton/meter$^2$ | 1.00 E + 2* |
| millimeter of mercury (0°C) | newton/meter$^2$ | 1.333 224 E + 2 |
| pascal | newton/meter$^2$ | 1.00 E + 0* |
| psi (lbf/inch$^2$) | newton/meter$^2$ | 6.894 757 2 E + 3 |
| torr (0°C) | newton/meter$^2$ | 1.333 22 E + 2 |
| ***Speed*** | | |
| foot/second | meter/second | 3.048 E − 1* |

■ **TABLE A.1 (continued)**

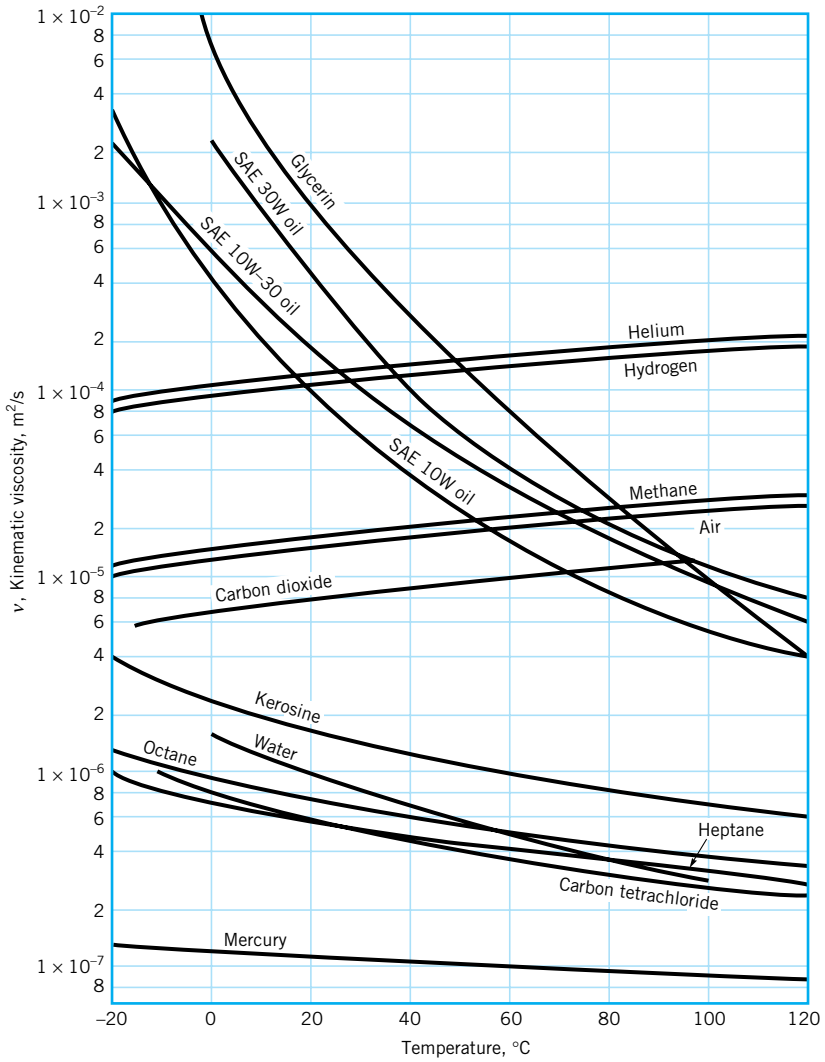
| To convert from | to | Multiply by |
|---|---|---|
| inch/second | meter/second | 2.54 E − 2* |
| kilometer/hour | meter/second | 2.777 777 8 E − 1 |
| knot (international) | meter/second | 5.144 444 444 E − 1 |
| mile/hour (U.S. statute) | meter/second | 4.4704 E − 1* |
| ***Temperature*** | | |
| Celsius | kelvin | $t_K = t_C + 273.15$ |
| Fahrenheit | kelvin | $t_K = (5/9)(t_F + 459.67)$ |
| Fahrenheit | Celsius | $t_C = (5/9)(t_F - 32)$ |
| Rankine | kelvin | $t_K = (5/9)t_R$ |
| ***Time*** | | |
| day (mean solar) | second (mean solar) | 8.64 E + 4* |
| hour (mean solar) | second (mean solar) | 3.60 E + 3* |
| minute (mean solar) | second (mean solar) | 6.00 E + 1* |
| year (calendar) | second (mean solar) | 3.1536 E + 7* |
| ***Viscosity*** | | |
| centistoke | meter$^2$/second | 1.00 E − 6* |
| stoke | meter$^2$/second | 1.00 E − 4* |
| foot$^2$/second | meter$^2$/second | 9.290 304 E − 2* |
| centipoise | newton second/meter$^2$ | 1.00 E − 3* |
| lbm/foot second | newton second/meter$^2$ | 1.488 163 9 E + 0 |
| lbf second/foot$^2$ | newton second/meter$^2$ | 4.788 025 8 E + 1 |
| poise | newton second/meter$^2$ | 1.00 E − 1* |
| poundal second/foot$^2$ | newton second/meter$^2$ | 1.488 163 9 E + 0 |
| slug/foot second | newton second/meter$^2$ | 4.788 025 8 E + 1 |
| rhe | meter$^2$/newton second | 1.00 E + 1* |
| ***Volume*** | | |
| acre foot | meter$^3$ | 1.233 481 837 547 52 E + 3* |
| barrel (petroleum, 42 gallons) | meter$^3$ | 1.589 873 E − 1 |
| board foot | meter$^3$ | 2.359 737 216 E − 3* |
| bushel (U.S.) | meter$^3$ | 3.523 907 016 688 E − 2* |
| cord | meter$^3$ | 3.624 556 3 E + 0 |
| cup | meter$^3$ | 2.365 882 365 E − 4* |
| dram (U.S. fluid) | meter$^3$ | 3.696 691 195 312 5 E − 6* |
| fluid ounce (U.S.) | meter$^3$ | 2.957 352 956 25 E − 5* |
| foot$^3$ | meter$^3$ | 2.831 684 659 2 E − 2* |
| gallon (U.K. liquid) | meter$^3$ | 4.546 087 E − 3 |
| gallon (U.S. liquid) | meter$^3$ | 3.785 411 784 E − 3* |
| inch$^3$ | meter$^3$ | 1.638 706 4 E − 5* |
| liter | meter$^3$ | 1.00 E − 3* |
| ounce (U.S. fluid) | meter$^3$ | 2.957 352 956 25 E − 5* |
| peck (U.S.) | meter$^3$ | 8.809 767 541 72 E − 3* |
| pint (U.S. liquid) | meter$^3$ | 4.731 764 73 E − 4* |
| quart (U.S. liquid) | meter$^3$ | 9.463 529 5 E − 4 |
| stere | meter$^3$ | 1.00 E + 0* |
| tablespoon | meter$^3$ | 1.478 676 478 125 E − 5* |
| teaspoon | meter$^3$ | 4.928 921 593 75 E − 6* |
| yard$^3$ | meter$^3$ | 7.645 548 579 84 E − 1* |

APPENDIX B

# Physical Properties of Fluids




■ **FIGURE B.1** **Dynamic (absolute) viscosity of common fluids as a function of temperature. To convert to BG units of lb·s/ft$^2$ multiply N·s/m$^2$ by 2.089 × 10$^{-2}$. (Curves from R. W. Fox and A. T. McDonald, *Introduction to Fluid Mechanics*, 3rd Ed., Wiley, New York, 1985. Used by permission.)**




■ **FIGURE B.2** **Kinematic viscosity of common fluids (at atmospheric pressure) as a function of temperature. To convert to BG units of $ft^2/s$ multiply $m^2/s$ by 10.76. (Curves from R. W. Fox and A. T. McDonald, *Introduction to Fluid Mechanics*, 3rd Ed., Wiley, New York, 1985. Used by permission.)**

## ■ TABLE B.1
**Physical Properties of Water (BG Units)[a]**

| Temperature (°F) | Density, $\rho$ (slugs/ft$^3$) | Specific Weight[b], $\gamma$ (lb/ft$^3$) | Dynamic Viscosity, $\mu$ (lb·s/ft$^2$) | Kinematic Viscosity, $\nu$ (ft$^2$/s) | Surface Tension[c], $\sigma$ (lb/ft) | Vapor Pressure, $p_v$ [lb/in.$^2$(abs)] | Speed of Sound[d], $c$ (ft/s) |
|---|---|---|---|---|---|---|---|
| 32 | 1.940 | 62.42 | 3.732 E − 5 | 1.924 E − 5 | 5.18 E − 3 | 8.854 E − 2 | 4603 |
| 40 | 1.940 | 62.43 | 3.228 E − 5 | 1.664 E − 5 | 5.13 E − 3 | 1.217 E − 1 | 4672 |
| 50 | 1.940 | 62.41 | 2.730 E − 5 | 1.407 E − 5 | 5.09 E − 3 | 1.781 E − 1 | 4748 |
| 60 | 1.938 | 62.37 | 2.344 E − 5 | 1.210 E − 5 | 5.03 E − 3 | 2.563 E − 1 | 4814 |
| 70 | 1.936 | 62.30 | 2.037 E − 5 | 1.052 E − 5 | 4.97 E − 3 | 3.631 E − 1 | 4871 |
| 80 | 1.934 | 62.22 | 1.791 E − 5 | 9.262 E − 6 | 4.91 E − 3 | 5.069 E − 1 | 4819 |
| 90 | 1.931 | 62.11 | 1.500 E − 5 | 8.233 E − 6 | 4.86 E − 3 | 6.979 E − 1 | 4960 |
| 100 | 1.927 | 62.00 | 1.423 E − 5 | 7.383 E − 6 | 4.79 E − 3 | 9.493 E − 1 | 4995 |
| 120 | 1.918 | 61.71 | 1.164 E − 5 | 6.067 E − 6 | 4.67 E − 3 | 1.692 E + 0 | 5049 |
| 140 | 1.908 | 61.38 | 9.743 E − 6 | 5.106 E − 6 | 4.53 E − 3 | 2.888 E + 0 | 5091 |
| 160 | 1.896 | 61.00 | 8.315 E − 6 | 4.385 E − 6 | 4.40 E − 3 | 4.736 E + 0 | 5101 |
| 180 | 1.883 | 60.58 | 7.207 E − 6 | 3.827 E − 6 | 4.26 E − 3 | 7.507 E + 0 | 5195 |
| 200 | 1.869 | 60.12 | 6.342 E − 6 | 3.393 E − 6 | 4.12 E − 3 | 1.152 E + 1 | 5089 |
| 212 | 1.860 | 59.83 | 5.886 E − 6 | 3.165 E − 6 | 4.04 E − 3 | 1.469 E + 1 | 5062 |

[a]Based on data from *Handbook of Chemistry and Physics*, 69th Ed., CRC Press, 1988. Where necessary, values obtained by interpolation.
[b]Density and specific weight are related through the equation $\gamma = \rho g$. For this table, $g = 32.174$ ft/s$^2$.
[c]In contact with air.
[d]From R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.

## ■ TABLE B.2
**Physical Properties of Water (SI Units)[a]**

| Temperature (°C) | Density, $\rho$ (kg/m$^3$) | Specific Weight[b], $\gamma$ (kN/m$^3$) | Dynamic Viscosity, $\mu$ (N·s/m$^2$) | Kinematic Viscosity, $\nu$ (m$^2$/s) | Surface Tension[c], $\sigma$ (N/m) | Vapor Pressure, $p_v$ [N/m$^2$(abs)] | Speed of Sound[d], $c$ (m/s) |
|---|---|---|---|---|---|---|---|
| 0 | 999.9 | 9.806 | 1.787 E − 3 | 1.787 E − 6 | 7.56 E − 2 | 6.105 E + 2 | 1403 |
| 5 | 1000.0 | 9.807 | 1.519 E − 3 | 1.519 E − 6 | 7.49 E − 2 | 8.722 E + 2 | 1427 |
| 10 | 999.7 | 9.804 | 1.307 E − 3 | 1.307 E − 6 | 7.42 E − 2 | 1.228 E + 3 | 1447 |
| 20 | 998.2 | 9.789 | 1.002 E − 3 | 1.004 E − 6 | 7.28 E − 2 | 2.338 E + 3 | 1481 |
| 30 | 995.7 | 9.765 | 7.975 E − 4 | 8.009 E − 7 | 7.12 E − 2 | 4.243 E + 3 | 1507 |
| 40 | 992.2 | 9.731 | 6.529 E − 4 | 6.580 E − 7 | 6.96 E − 2 | 7.376 E + 3 | 1526 |
| 50 | 988.1 | 9.690 | 5.468 E − 4 | 5.534 E − 7 | 6.79 E − 2 | 1.233 E + 4 | 1541 |
| 60 | 983.2 | 9.642 | 4.665 E − 4 | 4.745 E − 7 | 6.62 E − 2 | 1.992 E + 4 | 1552 |
| 70 | 977.8 | 9.589 | 4.042 E − 4 | 4.134 E − 7 | 6.44 E − 2 | 3.116 E + 4 | 1555 |
| 80 | 971.8 | 9.530 | 3.547 E − 4 | 3.650 E − 7 | 6.26 E − 2 | 4.734 E + 4 | 1555 |
| 90 | 965.3 | 9.467 | 3.147 E − 4 | 3.260 E − 7 | 6.08 E − 2 | 7.010 E + 4 | 1550 |
| 100 | 958.4 | 9.399 | 2.818 E − 4 | 2.940 E − 7 | 5.89 E − 2 | 1.013 E + 5 | 1543 |

[a]Based on data from *Handbook of Chemistry and Physics*, 69th Ed., CRC Press, 1988.
[b]Density and specific weight are related through the equation $\gamma = \rho g$. For this table, $g = 9.807$ m/s$^2$.
[c]In contact with air.
[d]From R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.

## ■ TABLE B.3

**Physical Properties of Air at Standard Atmospheric Pressure (BG Units)[a]**

| Temperature (°F) | Density, $\rho$ (slugs/ft$^3$) | Specific Weight[b], $\gamma$ (lb/ft$^3$) | Dynamic Viscosity, $\mu$ (lb·s/ft$^2$) | Kinematic Viscosity, $\nu$ (ft$^2$/s) | Specific Heat Ratio, $k$ (—) | Speed of Sound, $c$ (ft/s) |
|---|---|---|---|---|---|---|
| −40 | 2.939 E − 3 | 9.456 E − 2 | 3.29 E − 7 | 1.12 E − 4 | 1.401 | 1004 |
| −20 | 2.805 E − 3 | 9.026 E − 2 | 3.34 E − 7 | 1.19 E − 4 | 1.401 | 1028 |
| 0 | 2.683 E − 3 | 8.633 E − 2 | 3.38 E − 7 | 1.26 E − 4 | 1.401 | 1051 |
| 10 | 2.626 E − 3 | 8.449 E − 2 | 3.44 E − 7 | 1.31 E − 4 | 1.401 | 1062 |
| 20 | 2.571 E − 3 | 8.273 E − 2 | 3.50 E − 7 | 1.36 E − 4 | 1.401 | 1074 |
| 30 | 2.519 E − 3 | 8.104 E − 2 | 3.58 E − 7 | 1.42 E − 4 | 1.401 | 1085 |
| 40 | 2.469 E − 3 | 7.942 E − 2 | 3.60 E − 7 | 1.46 E − 4 | 1.401 | 1096 |
| 50 | 2.420 E − 3 | 7.786 E − 2 | 3.68 E − 7 | 1.52 E − 4 | 1.401 | 1106 |
| 60 | 2.373 E − 3 | 7.636 E − 2 | 3.75 E − 7 | 1.58 E − 4 | 1.401 | 1117 |
| 70 | 2.329 E − 3 | 7.492 E − 2 | 3.82 E − 7 | 1.64 E − 4 | 1.401 | 1128 |
| 80 | 2.286 E − 3 | 7.353 E − 2 | 3.86 E − 7 | 1.69 E − 4 | 1.400 | 1138 |
| 90 | 2.244 E − 3 | 7.219 E − 2 | 3.90 E − 7 | 1.74 E − 4 | 1.400 | 1149 |
| 100 | 2.204 E − 3 | 7.090 E − 2 | 3.94 E − 7 | 1.79 E − 4 | 1.400 | 1159 |
| 120 | 2.128 E − 3 | 6.846 E − 2 | 4.02 E − 7 | 1.89 E − 4 | 1.400 | 1180 |
| 140 | 2.057 E − 3 | 6.617 E − 2 | 4.13 E − 7 | 2.01 E − 4 | 1.399 | 1200 |
| 160 | 1.990 E − 3 | 6.404 E − 2 | 4.22 E − 7 | 2.12 E − 4 | 1.399 | 1220 |
| 180 | 1.928 E − 3 | 6.204 E − 2 | 4.34 E − 7 | 2.25 E − 4 | 1.399 | 1239 |
| 200 | 1.870 E − 3 | 6.016 E − 2 | 4.49 E − 7 | 2.40 E − 4 | 1.398 | 1258 |
| 300 | 1.624 E − 3 | 5.224 E − 2 | 4.97 E − 7 | 3.06 E − 4 | 1.394 | 1348 |
| 400 | 1.435 E − 3 | 4.616 E − 2 | 5.24 E − 7 | 3.65 E − 4 | 1.389 | 1431 |
| 500 | 1.285 E − 3 | 4.135 E − 2 | 5.80 E − 7 | 4.51 E − 4 | 1.383 | 1509 |
| 750 | 1.020 E − 3 | 3.280 E − 2 | 6.81 E − 7 | 6.68 E − 4 | 1.367 | 1685 |
| 1000 | 8.445 E − 4 | 2.717 E − 2 | 7.85 E − 7 | 9.30 E − 4 | 1.351 | 1839 |
| 1500 | 6.291 E − 4 | 2.024 E − 2 | 9.50 E − 7 | 1.51 E − 3 | 1.329 | 2114 |

[a]Based on data from R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.

[b]Density and specific weight are related through the equation $\gamma = \rho g$. For this table $g = 32.174$ ft/s$^2$.

## ■ TABLE B.4

**Physical Properties of Air at Standard Atmospheric Pressure (SI Units)[a]**

| Temperature (°C) | Density, $\rho$ (kg/m$^3$) | Specific Weight[b], $\gamma$ (N/m$^3$) | Dynamic Viscosity, $\mu$ (N·s/m$^2$) | Kinematic Viscosity, $\nu$ (m$^2$/s) | Specific Heat Ratio, $k$ (—) | Speed of Sound, $c$ (m/s) |
|---|---|---|---|---|---|---|
| −40 | 1.514 | 14.85 | 1.57 E − 5 | 1.04 E − 5 | 1.401 | 306.2 |
| −20 | 1.395 | 13.68 | 1.63 E − 5 | 1.17 E − 5 | 1.401 | 319.1 |
| 0 | 1.292 | 12.67 | 1.71 E − 5 | 1.32 E − 5 | 1.401 | 331.4 |
| 5 | 1.269 | 12.45 | 1.73 E − 5 | 1.36 E − 5 | 1.401 | 334.4 |
| 10 | 1.247 | 12.23 | 1.76 E − 5 | 1.41 E − 5 | 1.401 | 337.4 |
| 15 | 1.225 | 12.01 | 1.80 E − 5 | 1.47 E − 5 | 1.401 | 340.4 |
| 20 | 1.204 | 11.81 | 1.82 E − 5 | 1.51 E − 5 | 1.401 | 343.3 |
| 25 | 1.184 | 11.61 | 1.85 E − 5 | 1.56 E − 5 | 1.401 | 346.3 |
| 30 | 1.165 | 11.43 | 1.86 E − 5 | 1.60 E − 5 | 1.400 | 349.1 |
| 40 | 1.127 | 11.05 | 1.87 E − 5 | 1.66 E − 5 | 1.400 | 354.7 |
| 50 | 1.109 | 10.88 | 1.95 E − 5 | 1.76 E − 5 | 1.400 | 360.3 |
| 60 | 1.060 | 10.40 | 1.97 E − 5 | 1.86 E − 5 | 1.399 | 365.7 |
| 70 | 1.029 | 10.09 | 2.03 E − 5 | 1.97 E − 5 | 1.399 | 371.2 |
| 80 | 0.9996 | 9.803 | 2.07 E − 5 | 2.07 E − 5 | 1.399 | 376.6 |
| 90 | 0.9721 | 9.533 | 2.14 E − 5 | 2.20 E − 5 | 1.398 | 381.7 |
| 100 | 0.9461 | 9.278 | 2.17 E − 5 | 2.29 E − 5 | 1.397 | 386.9 |
| 200 | 0.7461 | 7.317 | 2.53 E − 5 | 3.39 E − 5 | 1.390 | 434.5 |
| 300 | 0.6159 | 6.040 | 2.98 E − 5 | 4.84 E − 5 | 1.379 | 476.3 |
| 400 | 0.5243 | 5.142 | 3.32 E − 5 | 6.34 E − 5 | 1.368 | 514.1 |
| 500 | 0.4565 | 4.477 | 3.64 E − 5 | 7.97 E − 5 | 1.357 | 548.8 |
| 1000 | 0.2772 | 2.719 | 5.04 E − 5 | 1.82 E − 4 | 1.321 | 694.8 |

[a]Based on data from R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.

[b]Density and specific weight are related through the equation $\gamma = \rho g$. For this table $g = 9.807$ m/s$^2$.

# APPENDIX C

# Properties of the U.S. Standard Atmosphere

**TABLE C.1**

**Properties of the U.S. Standard Atmosphere (BG Units)[a]**

| Altitude (ft) | Temperature (°F) | Acceleration of Gravity, $g$ (ft/s$^2$) | Pressure, $p$ [lb/in.$^2$(abs)] | Density, $\rho$ (slugs/ft$^3$) | Dynamic Viscosity, $\mu$ (lb·s/ft$^2$) |
|---|---|---|---|---|---|
| −5,000 | 76.84 | 32.189 | 17.554 | 2.745 E − 3 | 3.836 E − 7 |
| 0 | 59.00 | 32.174 | 14.696 | 2.377 E − 3 | 3.737 E − 7 |
| 5,000 | 41.17 | 32.159 | 12.228 | 2.048 E − 3 | 3.637 E − 7 |
| 10,000 | 23.36 | 32.143 | 10.108 | 1.756 E − 3 | 3.534 E − 7 |
| 15,000 | 5.55 | 32.128 | 8.297 | 1.496 E − 3 | 3.430 E − 7 |
| 20,000 | −12.26 | 32.112 | 6.759 | 1.267 E − 3 | 3.324 E − 7 |
| 25,000 | −30.05 | 32.097 | 5.461 | 1.066 E − 3 | 3.217 E − 7 |
| 30,000 | −47.83 | 32.082 | 4.373 | 8.907 E − 4 | 3.107 E − 7 |
| 35,000 | −65.61 | 32.066 | 3.468 | 7.382 E − 4 | 2.995 E − 7 |
| 40,000 | −69.70 | 32.051 | 2.730 | 5.873 E − 4 | 2.969 E − 7 |
| 45,000 | −69.70 | 32.036 | 2.149 | 4.623 E − 4 | 2.969 E − 7 |
| 50,000 | −69.70 | 32.020 | 1.692 | 3.639 E − 4 | 2.969 E − 7 |
| 60,000 | −69.70 | 31.990 | 1.049 | 2.256 E − 4 | 2.969 E − 7 |
| 70,000 | −67.42 | 31.959 | 0.651 | 1.392 E − 4 | 2.984 E − 7 |
| 80,000 | −61.98 | 31.929 | 0.406 | 8.571 E − 5 | 3.018 E − 7 |
| 90,000 | −56.54 | 31.897 | 0.255 | 5.610 E − 5 | 3.052 E − 7 |
| 100,000 | −51.10 | 31.868 | 0.162 | 3.318 E − 5 | 3.087 E − 7 |
| 150,000 | 19.40 | 31.717 | 0.020 | 3.658 E − 6 | 3.511 E − 7 |
| 200,000 | −19.78 | 31.566 | 0.003 | 5.328 E − 7 | 3.279 E − 7 |
| 250,000 | −88.77 | 31.415 | 0.000 | 6.458 E − 8 | 2.846 E − 7 |

[a]Data abridged from *U.S. Standard Atmosphere*, 1976, U.S. Government Printing Office, Washington, D.C.

## ■ TABLE C.2

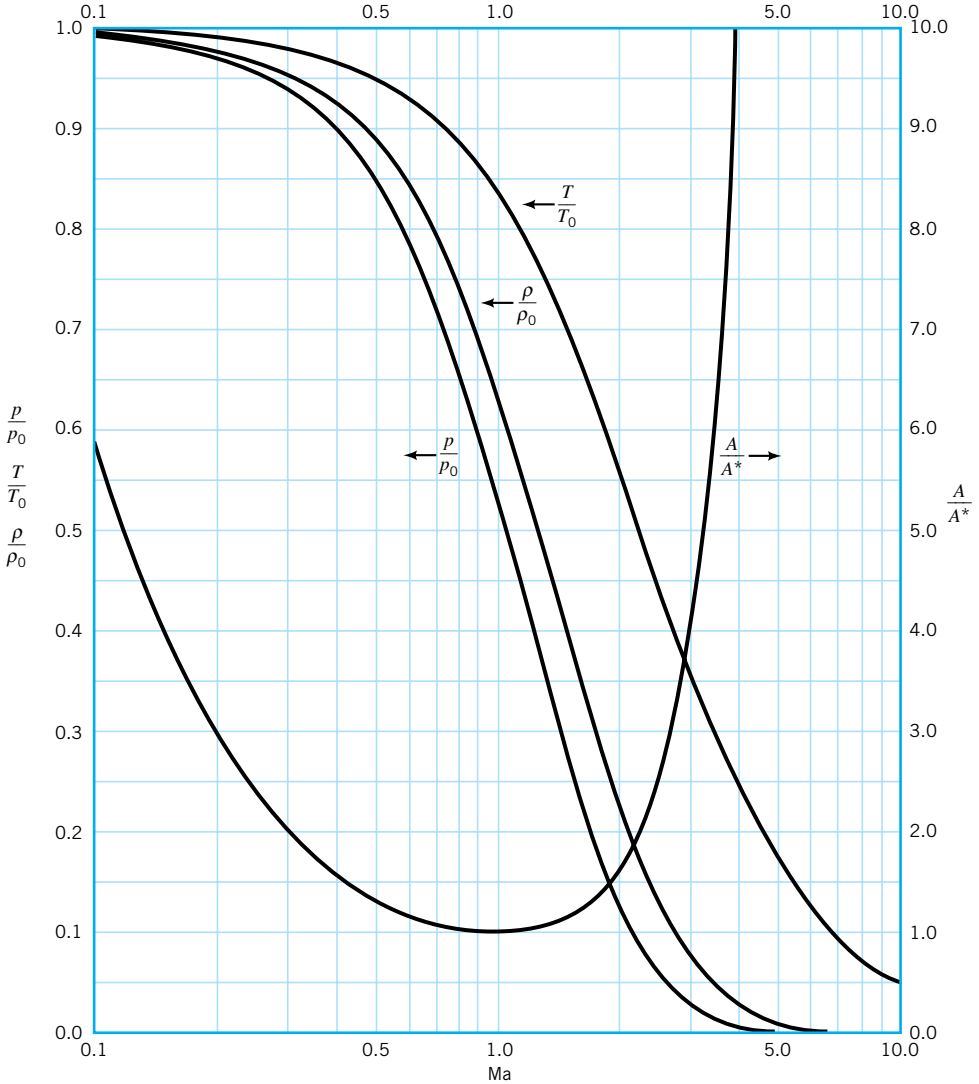
**Properties of the U.S. Standard Atmosphere (SI Units)[a]**

| Altitude (m) | Temperature (°C) | Acceleration of Gravity, $g$ (m/s$^2$) | Pressure, $p$ [N/m$^2$(abs)] | Density, $\rho$ (kg/m$^3$) | Dynamic Viscosity, $\mu$ (N·s/m$^2$) |
|---|---|---|---|---|---|
| −1,000 | 21.50 | 9.810 | 1.139 E + 5 | 1.347 E + 0 | 1.821 E − 5 |
| 0 | 15.00 | 9.807 | 1.013 E + 5 | 1.225 E + 0 | 1.789 E − 5 |
| 1,000 | 8.50 | 9.804 | 8.988 E + 4 | 1.112 E + 0 | 1.758 E − 5 |
| 2,000 | 2.00 | 9.801 | 7.950 E + 4 | 1.007 E + 0 | 1.726 E − 5 |
| 3,000 | −4.49 | 9.797 | 7.012 E + 4 | 9.093 E − 1 | 1.694 E − 5 |
| 4,000 | −10.98 | 9.794 | 6.166 E + 4 | 8.194 E − 1 | 1.661 E − 5 |
| 5,000 | −17.47 | 9.791 | 5.405 E + 4 | 7.364 E − 1 | 1.628 E − 5 |
| 6,000 | −23.96 | 9.788 | 4.722 E + 4 | 6.601 E − 1 | 1.595 E − 5 |
| 7,000 | −30.45 | 9.785 | 4.111 E + 4 | 5.900 E − 1 | 1.561 E − 5 |
| 8,000 | −36.94 | 9.782 | 3.565 E + 4 | 5.258 E − 1 | 1.527 E − 5 |
| 9,000 | −43.42 | 9.779 | 3.080 E + 4 | 4.671 E − 1 | 1.493 E − 5 |
| 10,000 | −49.90 | 9.776 | 2.650 E + 4 | 4.135 E − 1 | 1.458 E − 5 |
| 15,000 | −56.50 | 9.761 | 1.211 E + 4 | 1.948 E − 1 | 1.422 E − 5 |
| 20,000 | −56.50 | 9.745 | 5.529 E + 3 | 8.891 E − 2 | 1.422 E − 5 |
| 25,000 | −51.60 | 9.730 | 2.549 E + 3 | 4.008 E − 2 | 1.448 E − 5 |
| 30,000 | −46.64 | 9.715 | 1.197 E + 3 | 1.841 E − 2 | 1.475 E − 5 |
| 40,000 | −22.80 | 9.684 | 2.871 E + 2 | 3.996 E − 3 | 1.601 E − 5 |
| 50,000 | −2.50 | 9.654 | 7.978 E + 1 | 1.027 E − 3 | 1.704 E − 5 |
| 60,000 | −26.13 | 9.624 | 2.196 E + 1 | 3.097 E − 4 | 1.584 E − 5 |
| 70,000 | −53.57 | 9.594 | 5.221 E + 0 | 8.283 E − 5 | 1.438 E − 5 |
| 80,000 | −74.51 | 9.564 | 1.052 E + 0 | 1.846 E − 5 | 1.321 E − 5 |

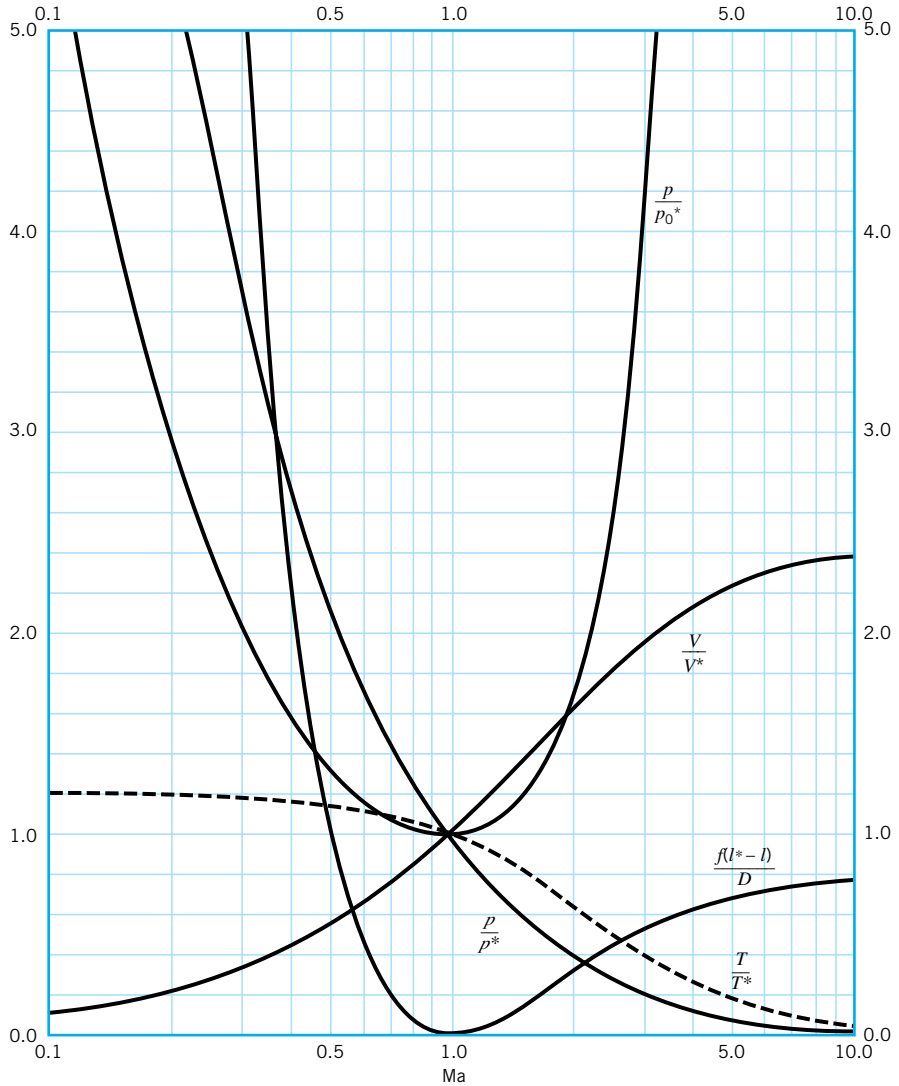
[a]Data abridged from *U.S. Standard Atmosphere*, 1976, U.S. Government Printing Office, Washington, D.C.

APPENDIX D

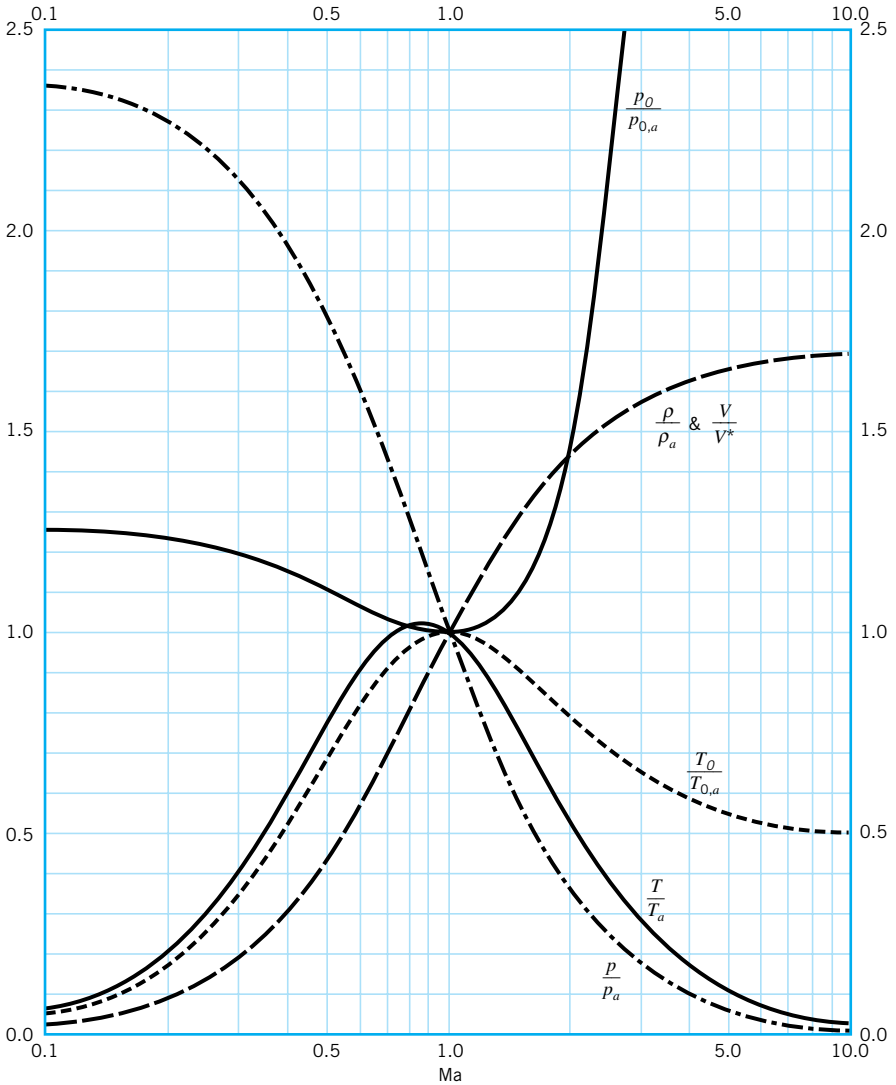
# *Compressible Flow Graphs for an Ideal Gas ($k = 1.4$)*



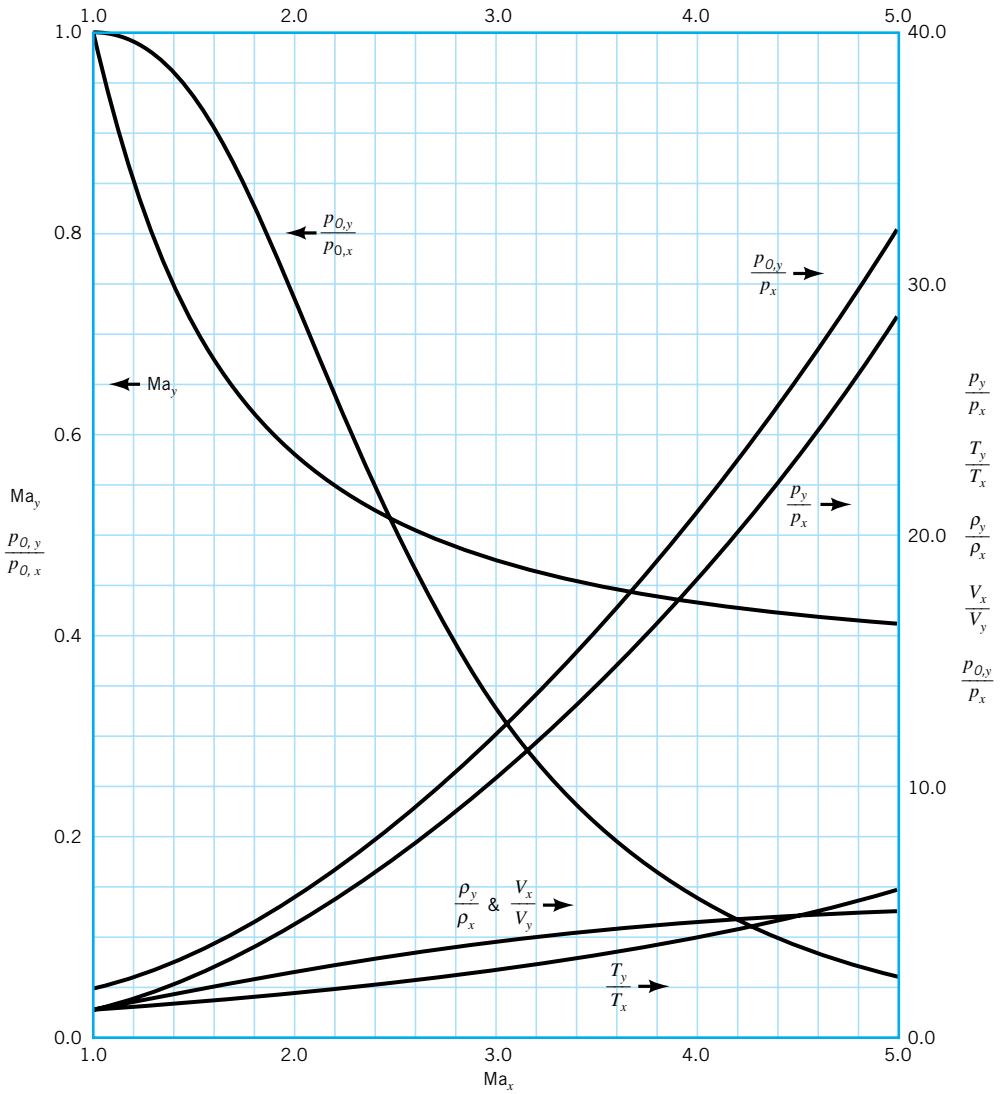

■ **FIGURE D.1** **Isentropic flow of an ideal gas with $k = 1.4$. (Graph provided by Professor Bruce A. Reichert of Kansas State University.)**




■ **FIGURE D.2** **Fanno flow of an ideal gas with $k = 1.4$. (Graph provided by Professor Bruce A. Reichert of Kansas State University.)**




■ **FIGURE D.3** **Rayleigh flow of an ideal gas with $k = 1.4$. (Graph provided by Professor Bruce A. Reichert of Kansas State University.)**




■ **FIGURE D.4** **Normal shock flow of an ideal gas with $k = 1.4$. (Graph provided by Professor Bruce A. Reichert of Kansas State University.)**