The three types of heat transfer are conduction, convection, and radiation.Heat transfer occurs when thermal energy moves from one place to another. Atoms and molecules inherently have kinetic and thermal energy, so all matter participates in heat transfer. There are three main types of heat transfer, plus other processes that move energy from high temperature to low temperature.Heat transfer is the movement of heat due to a temperature difference between a system and its surroundings. The energy transfer is always from higher temperature to lower temperature, due to the second law of thermodynamics. The units of heat transfer are the joule (J), calorie (cal), and kilocalorie (kcal). The unit for the rate of heat transfer is the kilowatt (KW).The three types of heat transfer differ according to the nature of the medium that transmits heat:Conduction requires contact.Convection requires fluid flow.Radiation does not require any medium.Conduction is heat transfer directly between neighboring atoms or molecules. Usually, it is heat transfer through a solid. For example, the metal handle of a pan on a stove becomes hot due to convection. Touching the hot pan conducts heat to your hand.Convection is heat transfer via the movement of a fluid, such as air or water. Heating water on a stove is a good example. The water at the top of the pot becomes hot because water near the heat source rises. Another example is the movement of air around a campfire. Hot air rises, transferring heat upward. Meanwhile, the partial vacuum left by this movement draws in cool outside air that feeds the fire with fresh oxygen.Radiation is the emission of electromagnetic radiation. While it occurs through a medium, it does not require one. For example, it's warm outside on a sunny day because solar radiation crosses space and heats the atmosphere. The burner element of a stove also emits radiation. However, some heat from a burner comes from conduction between the hot element and a metal pan. Most real-life processes involve multiple forms of heat transfer.Conduction requires that molecules touch each other, making it a slower process than convection or radiation. Atoms and molecules with a lot of energy have more kinetic energy and engage in more collisions with other matter. They are "hot." When hot matter interacts with cold matter, some energy gets transferred during the collision. This drives conduction. Forms of matter that readily conduct heat are called thermal conductors.Conduction is a common process in everyday life. For example:Holding an ice cube immediately makes your hands feel cold. Meanwhile, the heat transferred from your skin to the ice melts it into liquid water.Walking barefoot on a hot road or sunny beach burns your feet because the solid material transmits heat into your foot.Iron clothes transfers heat from the iron to the fabric.The handle of a coffee cup filled with hot coffee becomes warm or even hot via conduction through the mug material.One equation for conduction calculates heat transfer per unit of time from thermal conductivity, area, thickness of the material, and the temperature difference between two regions:Q = [K • A • (Thot – Tcold)] / dQ is heat transfer per unit timeK is the coefficient of thermal conductivity of the substanceA is the area of heat transferThot is the temperature of the hot regionTcold is the temperature of the cold regiond is the thickness of the bodyConvection is the movement of fluid molecules from higher temperature to lower temperature regions. Changing the temperature of a fluid affects its density, producing convection currents. If the volume of a fluid increases, than its density decreases and it becomes buoyant.Convection is a familiar process on Earth, primarily involving air or water. However, it applies to other fluids, such as refrigeration gasses and magma. Examples of convection include:Boiling water undergoes convection as less dense hot molecules rise through higher density cooler molecules.Hot air rises and cooler air sinks and replaces it.Convection drives global circulation in the oceans between the equators and poles.A convection oven circulates hot air and cooks more evenly than one that only uses heating elements or a gas flame.The equation for the rate of convection relates area and the difference between the fluid temperature and surface temperature:Q = hc • A • (Ts – Tf)Q is the heat transfer per unit timehc is the coefficient of convective heat transferA is the area of heat transferTs is the surface temperatureTf is the fluid temperatureRadiation is the release of electromagnetic energy. Another name for thermal radiation is radiant heat. Unlike conduction or convection, radiation requires no medium for heat transfer. So, radiation occurs both within a medium (solid, liquid, gas) or through a vacuum.There are many examples of radiation:A microwave oven emits microwave radiation, which increases the thermal energy in foodThe Sun emits light (including ultraviolet radiation) and heatUranium-238 emits alpha radiation as it decays into thorium-234The Stephan-Boltzmann law describes relationship between the power and temperature of thermal radiation:P = e • σ • A· (Tr – Tc)4P is the net power of radiationA is the area of radiationTr is the radiator temperatureTc is the surrounding temperaturee is emissivityσ is Stefan's constant (σ = 5.67 × 10-8Wm-2K-4)While conduction, convection, and radiation are the three modes of heat transfer, other processes absorb and release heat. For example, atoms release energy when chemical bonds break and absorb energy in order to form bonds. Releasing energy is an exergonic process, while absorbing energy is an endergonic process. Sometimes the energy is light or sound, but most of the time it's heat, making these processes exothermic and endothermic.Phase transitions between the states of matter also involve the absorption or release of energy. A great example of this is evaporative cooling, where the phase transition from a liquid into a vapor absorbs thermal energy from the environment.

Faghri, Amir; Zhang, Yuwen; Howell, John (2010). Advanced Heat and Mass Transfer. Columbia, MO: Global Digital Press. ISBN 978-0-9842760-0-4.Geankoplis, Christie John (2003). Transport Processes and Separation Principles (4th ed.). Prentice Hall. ISBN 0-13-101367-X.Peng, Z.; Doroodchi, E.; Moghtaderi, B. (2020). "Heat transfer modelling in Discrete Element Method (DEM)-based simulations of thermal processes: Theory and model development". Progress in Energy and Combustion Science. 79: 100847. doi:10.1016/j.pecs.2020.100847Welty, James R.; Wicks, Charles E.; Wilson, Robert Elliott (1976). Fundamentals of Momentum, Heat, and Mass Transfer (2nd ed.). New York: Wiley. ISBN 978-0-471-93354-0.

Related Posts There are three methods that facilitate heat transfer known as: Conduction Convection Radiation Radiation transfers heat using electromagnetic waves and does not involve any interaction between matter. The heat that comes from the sun is an example of radiation. Convection occurs in liquids and gasses and describes the movement of heat from one location to another facilitated by the movement of fluids. When heated, fluids expand and become less dense. The hot fluid rises and displaces the cold fluid above it, pushing it toward the heat source. This cold fluid will become heated and rise upwards, creating a constant flow of fluid from an area of high heat to low heat. Convection explains how baseboard radiators can heat a whole room. The hot air generated from the radiators flows quickly upwards, pushing the cold air down towards the heater on the floor, creating a constant airflow. See more examples of convection. Heat transfer through conduction involves the transfer of heat between two materials from surface contact. No matter is exchanged between materials, only energy. This type of heat transfer occurs in solid materials and is caused by particle vibrations. When exposed to a flow of energy, the particles in a solid begin to wiggle, rotate and vibrate, creating kinetic energy. A common example of conduction is heating a pan on a stove. The heat from the burner transfers directly to the pan's surface. Temperature measures the amount of kinetic energy processed by the particles in a sample of matter. The more kinetic energy a material has, its internal temperature will be higher. Heat Transfer in Metals Matter with high kinetic energy will also have a high thermal conductivity. Thermal conductivity describes how efficiently a material can pass heat through it. It is defined by the rate of energy flow per unit area when compared to a temperature gradient. Most conductivity values are expressed in Watts per meter per degree Kelvin W/m•K. Thermal conductivity explains why walking barefoot on a cold tile floor feels much cooler than walking on carpet, even though both are at room temperature. Tile and rocks have a higher thermal conductivity than carpet and fabrics, so they can transfer heat away from a foot at a much quicker rate, making the tile appear cool to the touch. Metals are an example of a material with a high thermal conductivity that can quickly transfer heat. The internal structure of a metal molecule contains free electrons that can move freely through the bulk of the material. These free electrons collide rapidly with other particles, causing a metal's internal structure to vibrate faster and heat up quicker. These rapid vibrations promote energy and heat flow throughout the metal. Metals like copper, aluminum and silver are frequently used to make thermal appliances and tools. Copper pipes are wires that are extremely popular to use within a home to transfer energy and heat quickly from one area to another. Aluminum has extremely similar thermal properties to copper and is often used as a cost-effective replacement to perform the same functions. Silver is one of the most widely used metals for thermal applications. Over 35% of all silver produced in the USA is manufactured for electronics or electrical uses. The demand for silver continues to grow as it is becoming a crucial component in producing solar panels. Other highly thermally conductive materials, such as diamonds, also have many practical applications. Diamond powder is often used in electronics to transfer heat away from sensitive areas to protect them from overheating. Figure 2: Standard solar panels that are frequently manufacture with silver Heat transfer in non-metals Non-metal materials rely on phonons to transfer heat along a gradient from cold to warm areas. Plastics, foams, and wood are all examples of materials with poor thermal conductivity values. These materials are known as insulators and can restrict the flow of heat. Insulators have numerous extremely useful applications that can protect energy from being lost to the environment. Foam is an extremely useful home and building insulation material. Over 50% of all household energy is used to heat or cool a home. Using a high thermal conductive material to insulate a house can substantially lower the energy required to heat or cool a building. Energy prices continuously increase globally, making it ideal to conserve as much power and heat as possible to lower power bills. Conclusion Thermal conductivity is an extremely important material property that enables thousands of production systems to function properly and efficiently. Heat is constantly being exchanged within every ecosystem in the form of lost energy. Harnessing thermal energy for industrial and practical processes has created excellent energy-saving technologies that are utilized daily. Heat can move through a system through conduction, radiation, and convection. Structure, density and material composition can impact a sample's thermal conductivity. Materials with high or low thermal conductivity values are used for various everyday applications. Although highly underestimated, life would not be the same without heat transfer and thermal exchange. For a deeper understanding of heat transfer mechanism, refer to the basics of heat transfer. Frequently Asked Questions What are 5 examples of conduction? Heating a Pan on a Stove: When you put a pan on a heated stove, the heat from the stove transfers to the pan's surface, which helps you cook your food. This is a classic example of conduction, in which heat moves from a hotter object (the stove burner) to a cooler one (the pan). Touching a Hot Cup of Coffee: Heat transfers into your hands through conduction when you hold a hot cup of coffee. The thermal energy moves from the hotter object (the cup) to the cooler one (your hands), making you feel the warmth. Ironing Clothes: Ironing clothes involves conduction. The iron is heated and then applied to the wrinkled fabric. The heat from the iron transfers to the clothes, smoothing out wrinkles. This heat transfer from the hot iron to the cooler clothes directly results from conduction. Walking on Hot Sand: On a sunny day, the sand at the beach can become very hot. When you walk on this hot sand, heat is conducted from the sand to your feet, making you feel the heat. The heat moves from the warmer sand to the cooler soles of your feet, another example of conduction. Melting Chocolate in Your Hand: If you hold a piece of chocolate in your hand, it will eventually start to melt because the heat from your hand is conducted to the cooler chocolate, raising its temperature until it melts. This process is a clear demonstration of heat conduction from your warmer hand to the cooler chocolate. What are 3 types of conduction? Heat Conduction (Thermal Conduction): This refers to transferring thermal energy through a material without the material itself moving. It occurs due to the temperature difference within the material, causing energy to transfer from the hotter part to the cooler part. Electric Conduction: This involves the transfer of electric charge through a conductor. Electric conduction allows electric current to flow through materials, typically metals, due to the movement of electrons or ions. Photoconductivity: This conduction type occurs when a material's electrical conductivity increases by absorbing electromagnetic radiation, such as light. Light absorption increases the number of free charge carriers, such as electrons and holes, enhancing the material's conductivity. References Shindé, S., & Goela, J. (2006). High thermal conductivity materials. New York: Springer. doi:10.1007/b106785]The Physics Classroom Tutorial. (n.d.). Retrieved from is thermal energy? (n.d.). Retrieved from Featured Image: Author: Kallista Wilson | Junior Technical Writer | Thermtest Conduction is one of the three modes of heat transfer while the other two are convection and radiation. There are several practical instances of conduction heat transfer in everyday life, in which heat is transferred without producing motion in the molecules of a substance.In this article, we're going to discuss:What is Conduction heat transfer?Fourier's law used for conduction heat transfer:2.1. Assumptions in Fourier law of heat conduction:Thermal conductivity and Thermal resistance:Conduction heat transfer equation:Types of conduction heat transfer:One dimensional steady state heat conduction:Conduction heat transfer examples:Conduction is the mode of heat transfer in which the transfer of heat from one position to another position is done by means of molecular vibration without changing its lattice position. The heat transfer by conduction is mostly considered in the case of solid materials in which the molecules has the same lattice position throughout the heat transfer process.It also occurs in liquid or gas molecules, When the motion of the molecules is not considered.The heat transfer by the conduction takes place by the molecular vibration and by the movement of electrons.Some of the real world examples of conduction are as follows:During the ironing of clothes, the heat is transferred from iron to cloth by conductionThe handle of the pan kept on the gas stove becomes hot even if it is not directly subjected to the heat. This occurs because the heat is transferred from the pan to the handle by conduction.The components attached to the vehicle engines become hot as it gains heat by conduction from the engine.The Fourier law of heat conduction states that the rate of heat transfer (Q) in a homogeneous solid material is directly proportional to the temperature gradient in the direction of heat flow (`\frac{dT}{dx}`) and area of a cross-section perpendicular to the direction of flow (A).Mathematically, the Fourier law can be expressed as,Q ∝ A `\frac{dt}{dx}`Q = – KA .`\frac{dt}{dx}`Where,`\frac{dt}{dx}` = Temperature gradient in the direction of heat flowA = Cross-sectional areaK = Thermal conductivityThe negative sign in equation of heat conduction indicates that the heat flows in direction of high temperature to low temperature. Thus, the negative sign compensates for the negative nature of the temperature gradient.The Fourier law of heat conduction has following assumptions:Thermal conductivity is constant throughout the material.No internal heat generation occurs in the body.There is a constant temperature gradient.The flow of heat is unidirectional and occurs in steady-state conditions.The surfaces are isothermal.Thermal conductivity is the ability of a material to transfer heat through it. Hence the material with higher thermal conductivity has a higher rate of heat transfer and the material with less thermal conductivity shows a lower rate of heat transfer. Thermal conductivity is denoted by the symbol 'K'.From the Fourier law of conduction, the magnitude of thermal conductivity can be given by,`K=\frac{Q}{A.\frac{dt}{dx}}`Therefore, the thermal conductivity can be defined as the rate of heat transfer per unit cross-sectional area and per unit temperature gradient in the direction of heat flow.The unit of thermal conductivity in the SI system is given by,`K=\frac{Q}{A.\frac{dt}{dx}}` = `\frac{W}{m^{2}.\frac{K}{m}}` =W/mKTherefore, the SI unit of thermal conductivity is W/m.KSimilarly the unit of thermal conductivity in FPS system is given by,`K=\frac{Q}{A.\frac{dt}{dx}}` = `\frac{\text{Btu/hr}}{ft^{2}.\frac{ ° F}{ft}}`K = Btu/hr.ft.°FTherefore, the FPS unit of thermal conductivity is Btu/hr.Ft.°F.Factors affecting thermal conductivity of materials:The thermal conductivity of a material is influenced by the following factors:1) Presence of free electrons:The free electrons easily travel into the material hence it can transfer the heat at a faster rate.Hence as the number of free electrons present in the material increases, the thermal conductivity of the material also increases.The number of free electrons present in metals is higher therefore metals have higher thermal conductivity.2) Presence of impurity:The thermal conductivity of the material is higher in its pure form. The thermal conductivity of material decreases with an increase in impurities or alloying elements.Example: The thermal conductivity of pure copper is higher than brass.3) Density:The thermal conductivity of material increases with an increase in its density because of the increase in the rate of molecular collision.4) Temperature:In the case of solid materials as the temperature increases, the vibration of molecules also increases, and therefore the movement of free electrons decreases, and hence the thermal conductivity decreases.In the case of liquids, as the temperature increases the density of liquid decreases. Therefore, the thermal conductivity of liquid decreases.5) Material structure:The crystalline structure has a higher rate of thermal conductivity while the amorphous material has a lesser value of thermal conductivity.6) Presence of moisture:The thermal conductivity of material increases with an increase in moisture content in the material.Thermal resistance is the resistance to the conduction heat transfer that is given by the ratio of the thickness of the object to the product of thermal conductivity and area of cross-section.Thermal resistance is also known as the reciprocal of thermal conductance.Mathematically it is expressed as,`R_{th}=\frac{x}{KA}`Therefore, the Fourier equation for heat conduction can be written as,`Q=-\frac{\Deltat}{R_{th}}`The SI unit of thermal resistance is given by,`R_{th}=\frac{x}{KA}` = `\frac{m}{[\frac{W}{m.K}][m^{2}]}``R_{th}=\frac{K}{W}`Therefore, SI unit of thermal resistance is K/WThe FPS unit of thermal resistance is given by,`R_{th}=\frac{x}{KA}` = `\frac{ft}{[\text{Btu/hr}.ft. °F][ft^{2}]}``R_{th}` = °F.hr/BtuTherefore, the FPS unit of thermal resistance is °F.hr/Btu.Thermal resistance for the composite section:The composite section consists of a number of layers of different materials. These layers are arranged in series in the direction of heat flow or in parallel to the direction of heat flow.Here are the methods to find the equivalent resistance for both types of arrangements.1) Layers in series:For n number of layers of heat transfering bodies arranged in series, the equivalent thermal resistance is given by,`R_{th(eq)}=R_{th(1)}+R_{th(2)}`+`R_{th(3)}+\cdots R_{th(n)}`2) Layers in parallel:For n number of heat transferring bodies arranged parallelly to the direction of heat flow, the equivalent thermal resistance is given by,`\frac{1}{R_{th(eq)}}=\frac{1}{R_{th(1)}}`+`\frac{1}{R_{th(2)}}+\cdots \frac{1}{R_{th(n)}}`The heat conduction equation shows the heat distribution in the object over time. The equations for heat conduction for the different coordinate systems are given below:-The general heat conduction equation in cartesian coordinates is given below:`\frac{\partial }{\partial x}(K_{x}\frac{\partial t}{\partial x})+\frac{\partial }{\partial y}(K_{y}\frac{\partial t}{\partial y})`+`\frac{\partial }{\partial z}(K_{z}\frac{\partial t}{\partial z})+q_{g}=\rho C\frac{\partial t}{\partial \tau }`Where,∂t/∂x = Temperature gradient along x-direction∂t/∂y = Temperature gradient along y direction∂t/∂z = Temperature gradient along z directionKx, Ky, Kz = Thermal conductivity in X, Y, and Z direction`q_{g}` = Rate of heat generation per unit volume∂t/∂τ = Rate of temperature change with respect to timeρ = Density of the materialC = Specific heatFor constant thermal conductivity:-For constant thermal conductivity in X, Y, and Z-direction, the equation is reduced as,`\frac{\partial ^{2}t}{\partial x^{2}}+\frac{\partial ^{2}t}{\partial y^{2}}`+`\frac{\partial ^{2}t}{\partial z^{2}}+\frac{q_{g}}{K}=\frac{1}{\alpha }\frac{\partial t}{\partial \tau }`Where, α = `\frac{K}{\rho\times C}` = Thermal diffusivityFor steady-state heat conduction with constant thermal conductivity:-For steady-state heat conduction (`\frac{\partial t}{\partial \tau }` = 0) with constant thermal conductivity, the equation can be reduced as,`\frac{\partial ^{2}t}{\partial x^{2}}+\frac{\partial ^{2}t}{\partial y^{2}}`+`\frac{\partial ^{2}t}{\partial z^{2}}+\frac{q_{g}}{K}=0`For no heat generation, steady-state conduction and for constant thermal conductivity:For no heat generation (`q_{g}=0`), steady-state conduction and for constant thermal conductivity, the equation can be reduced as,`\frac{\partial ^{2}t}{\partial x^{2}}+\frac{\partial ^{2}t}{\partial y^{2}}`+`\frac{\partial ^{2}t}{\partial z^{2}}=0`The equation is applicable for the objects having cylindrical shape.The general heat conduction equation in cylindrical coordinates is given by,`[\frac{\partial ^{2}t}{\partial r^{2}}+\frac{1}{r}\frac{\partial t}{\partial r}+\frac{1}{r^{2}}\frac{\partial ^{2}t}{\partial \phi ^{2}}`+`\frac{\partial ^{2}t}{\partial z^{2}}]+q_{g}=\frac{1}{\alpha }\frac{\partial t}{\partial \tau }`The equation is applicable for the object having spherical shape.General heat conduction equation in spherical coordinates is given by,`[\frac{1}{r^{2}sin^{2}\theta }.\frac{\partial ^{2}t}{\partial \phi ^{2}}`+`\frac{1}{r^{2}sin\theta }.\frac{\partial }{\partial \theta }(sin\theta \frac{\partial t}{\partial \theta })`+`\frac{1}{r^{2}}\frac{\partial }{\partial r }(r^{2} \frac{\partial t}{\partial r })]` + ` \frac{q_{g}}{K}=\frac{1}{\alpha }\frac{\partial t}{\partial \tau }`The conduction heat transfer is classified on the basis of temperature variation with respect to time and temperature variation with respect to distance.Based on temperature variation with respect to time, the conduction heat transfer is classified as,In steady state heat conduction, the temperature of an object doesn't change with respect to time or we can say that in steady-state conduction the change in temperature with respect to time is negligible.Mathematically it is stated as,`\frac{\partial t}{\partial \tau }=0`Where,∂t = Change in temperature∂`\tau` = Time intervalExample: Heat generated due to the electric current.In unsteady state heat conduction, the temperature of an object changes with respect to time.Hence in this case, the temperature change with respect to time is considerable.Mathematically it is expressed as,`\frac{\partial t}{\partial \tau }e 0`Example: Heating or Cooling of waterBased on temperature variation with respect to space, the conduction heat transfer is classified as,In one-dimensional heat conduction, the temperature gradient in the two dimensions is negligible in comparison with the third dimension.Mathematically, it is expressed as,`\frac{\partial ^{2}t}{\partial x^{2}}`>>`\frac{\partial ^{2}t}{\partial y^{2}}` and `\frac{\partial ^{2}t}{\partial z^{2}}``\therefore \frac{\partial ^{2}t}{\partial y^{2}}` and `\frac{\partial ^{2}t}{\partial z^{2}}\approx 0`In two-dimensional heat conduction, the temperature gradient in one dimension is negligible in comparison with the other two dimensions.Mathematically, it is expressed as,`\frac{\partial ^{2}t}{\partial x^{2}}` and `\frac{\partial ^{2}t}{\partial y^{2}}`>>`\frac{\partial ^{2}t}{\partial z^{2}}``\therefore \frac{\partial ^{2}t}{\partial z^{2}}\approx 0`In three-dimensional heat conduction, the temperature gradient is present in all three dimensions.`\frac{\partial ^{2}t}{\partial x^{2}}` and `\frac{\partial ^{2}t}{\partial y^{2}}` and `\frac{\partial ^{2}t}{\partial z^{2}}` `eq` 0Following are the different cases of one-dimensional steady-state heat transfer:-A) Heat conduction through a plane wall:-The one-dimensional steady-state heat conduction through the plane wall is given by,`Q=\frac{(t_{1}-t_{2})}{\frac{L}{KA}}`It is also written as,`Q=\frac{(t_{1}-t_{2})}{R_{th}}` —-[as `R_{th}=\frac{L}{KA}`]Where`t_{1}-t_{2}` = Temperature difference between two surfacesL = Thickness of the wallK = Thermal conductivity of the plane wallA = Area of a cross-section of plane wallB) Heat conduction through composite wall:The composite plane walls are made by arranging layers of the different materials in series or in parallel.1) Walls in series:For plane was arranged in series, the rate of heat transfer is given by,Q = `Q_{1-3} = Q_{1-2} = Q_{2-3}`Q=`\frac{t_{1}-t_{3}}{R_{th(A)}+R_{th(B)}}` = `\frac{t_{1}-t_{2}}{R_{th(A)}}` = `\frac{t_{2}-t_{3}}{R_{th(B)}}`Q=`\frac{t_{1}-t_{3}}{\frac{L_{A}}{K_{A}A_{A}}+\frac{L_{B}}{K_{B}A_{B}}}` = `\frac{t_{1}-t_{2}}{\frac{L_{A}}{K_{A}A_{A}}}` = `\frac{t_{2}-t_{3}}{\frac{L_{B}}{K_{B}A_{B}}}`2) Walls in parallel:For plain wall arranged parallel, the rate of heat transfer is given by,Q = `Q_{1} + Q_{2}`Q =`\frac{t_{1}-t_{2}}{\frac{L_{1}}{K_{1}A_{1}}}` + `\frac{t_{1}-t_{2}}{\frac{L_{2}}{K_{2}A_{2}}}`C) Heat conduction through hollow cylinder:The heat transfer by conduction through hollow cylindrical shape is given by,Q = `\frac{t_{1}-t_{2}}{\frac{ln(\frac{r_{2}}{r_{1}})}{2\pi KL}}`Where,`t_{1}` = Inner surface temperature`t_{2}` = Outer surface temperature`r_{1}` = Inner radius of cylinder`r_{2}` = Outer radius of cylinderK = Thermal conductivity of cylinderL = Length of cylinderFor cyclinder `R_{th}` =`\frac{ln(\frac{r_{2}}{r_{1}})}{2\pi KL}` , therefore the equation can also written as,Q =`\frac{t_{1}-t_{2}}{R_{th}}`D) Heat conduction through hollow sphere:The heat transfer by conduction through hollow sphere is given by,Q = `\frac{t_{1}-t_{2}}{\frac{(r_{2}-r_{1})}{4\pi K r_{1}r_{2}}}`Where,`r_{1}` = Inner radius of sphere`r_{2}` = Outer radius of sphereK = Thermal conductivity`t_{1}` = Inner surface temperature`t_{2}` = Outer surface temperatureFor sphere, the thermal resistance is given by`R_{th}` =`\frac{(r_{2}-r_{1})}{4\pi K r_{1}r_{2}}`Therefore the equation can also written as,Q = `\frac{t_{1}-t_{2}}{R_{th}}`1] For the wall shown below, the area perpendicular to the direction of flow is 1.5 m². The temperature at the left side of the wall is 1500°C and at the right side is 40°C. Thus find the rate of heat transfer through the wall. (`K_{A}` = 0.65 W/mK, `K_{B}` = 0.3 W/mK)Given:`K_{A}` = 0.65 W/mK`K_{B}` = 0.3 W/mKA = 1.5 m²`t_{1}` = 1500 °C = 1773 K`t_{2}` = 40 °C = 313 K`L_{A}` = 0.1 m`L_{B}` = 0.15 mSolution:Total thermal resistance for the wall is given as follows,`R_{th}` = `R_{th(1)}+R_{th(2)}``R_{th}` = `\frac{L_{A}}{K_{A}.A}` + `\frac{L_{B}}{K_{B}.A}``R_{th}` = `\frac{0.1}{0.65 \times 1.5}` + `\frac{0.15}{0.3 \times 1.5}``\mathbf{R_{th}}` = 0.435 K/WThe rate of heat transfer through the wall is given by,`Q=\frac{(t_{1}-t_{2})}{R_{th}}``Q=\frac{1773 – 313}{0.435}`This is the rate of heat transfer through the wall.2] The hollow cylinder has an inside radius of 0.5 m, an outside radius of 1 m, and a length of 1.5 m. The temperature on the inside surface of the cylindrical wall is 1650°C and on the outside surface is 25°C. Thus find the rate of heat transfer through the cylinder. (`K_{\text{cylinder}}` = 0.55 W/mK)Given:`K_{\text{cylinder}}` = 0.55 W/mK`r_{1}` = 0.5 m`r_{2}` = 1 m`t_{1}` = 1650°C = 1923 K`t_{2}` = 25 °C = 298 KL = 1.5 mSolution:The thermal resistance for the cylindrical surface is given by,`R_{th}` =`\frac{ln(\frac{r_{2}}{r_{1}})}{2\pi KL}``R_{th}` =`\frac{ln(\frac{1}{0.5})}{2\pi \times 0.55 \times 1.5}``R_{th}` = 0.1337 mThe heat transferred outside of the cylinder is given by,Q =`\frac{t_{1}-t_{2}}{R_{th}}`Q = `\frac{1923 – 298}{0.1337}`FAQs:What is an example of heat transfer by conduction?Examples of the heat transfer by conduction are as follows,1] Heat conducted during ironing of clothes2] Transfer of heat from the engine to fins.What are the types of conduction of heat?The conduction heat transfer can be classified as follows:Based on temperature variation with respect to time:1) Steady-state heat conduction2) Un-steady state heat conductionBased on temperature variation with respect to space:1) One-dimensional heat conduction2) Two-dimensional heat conduction3) Three-dimensional heat conductionHow does conduction work in ironing clothes?During ironing, the heat from the surface of the iron is conducted to the clothes without causing bulk motion of the molecules of iron or cloth. Examples of conduction of Heat Conduction Of heat transfer is the transfer of internal energy by microscopic collisions of the particles and the movement of free electrons within a body. Colliding particles, which contain molecules, atoms, and electrons, transfer kinetic energy and P.E, together called internal energy. Conduction of heat takes place in all phases of matter: solid, liquid, and gas. This post includes: Conduction of heat transfer definition Examples of conduction of heat Applications Lot's more Let's dive right now… The rate at which energy is conducted as the heat between two bodies depends on the temperature difference between the two bodies which are in contact with each other. The heat automatically flows from a hotter body to a colder body. For example, heat flows from the hot plate of a stove to the bottom of a saucepan in contact with it. In the process of conduction of heat, the heat flows within and through the object itself. On the other hand, in heat transfer by the thermal radiation, the heat transfer is often between bodies, which may be separated spatially. In convection heat transfer, the internal energy flows between bodies by moving material carriers. In the solids, conduction is carried out by the combination of collisions and vibration of molecules. In gases and liquids, conduction occurs due to collisions of molecules during their irregular motion. See Also: Difference between Heat and Temperature Examples of Conduction of Heat Transfer Here are some examples of conduction of Heat: Utensils used to handle charcoal or other very hot substances. Keep in mind that the extension is long so that the heat transfer is slower. The ice, when put in a cup of boiling water, melts completely. When you bring water to a boil, the gas stove flame transmits the heat to the pot, and from one moment to the next the water is already heated. The heat that comes from a kitchen utensil when you leave it on a container and turn over it a soup that is practically burning. Heat conduction in solids In solids, atoms and molecules are packed close together. They continue to vibrate about their mean position. What happens when one of its ends is heated? The atoms or molecules present at that end begin to vibrate more rapidly. They also collide with their neighboring atoms or molecules. In doing so, they pass some of their energy to neighboring atoms or molecules during collisions with them will increase in their vibrations. These atoms or molecules intern pass on a part of the energy to their neighboring particles. In this way, some heat reaches the other parts of the solids. This is a slow process and a very small transfer of heat takes place from hot to cold parts in solids. How do metals differ from non-metals in terms of conducting heat? Metals have free electrons. These free electrons move with very high velocities within the metal objects. They carry energy at a very fast rate from hot to cold parts of the object as they move. Thus, heat reaches the cold parts of the metal objects from their hard parts much more quickly than nonmetals. All metals are good conductors of heat. The substances through which heat does not conduct easily are called bad conductors or insulators. Wood,cork,cotton,wool,glass,rubber,etc are bad conductors or insulators. See Also: Difference between conductors and insulators Examples of conductive materials Pure silver Gallium Hardened copper (**) Nickel Aluminum Graphite Pure zinc Tantalum Phosphor bronze Bronze Nickel Steel Brass Galvanized metal Tungsten Iron Cast iron Copper Gold Ionized air Applications of conduction of heat in our daily life Use of good conductors of heat Cooking utensils, saucepans, kettles and boilers are made of metals where direct heating is involved. Soldering iron is made of iron with a tip made of copper because copper is a much better conductor of heat than iron. Use of insulators or bad conductors Some common applications of insulators are given: Handles of kettles and spoons are made of plastic or wood because wood is the poor conductor of heat. In this way, the hot kettles, utensils, and spoons can be picked up without burning our hands. Woolen clothes or blankets are used to keep people warm on cold days. Sawdust is used to cover up ice blocks because it has good insulating properties. Related Topics: convection heat transfer Radiation heat transfer Difference between conduction convection and radiation Difference between Conductors and Insulators

Heat can be transferred in three different modes: conduction, convection, and radiation.All modes of heat transfer require the existence of a temperature difference, and all modes are from the high-temperature medium to a lower temperature one.Heat is transferred by three primary modes:Conduction (Energy transfer in a solid)Convection (Energy transfer in a fluid)Radiation (Does not need a material to travel through)types of heat transferConduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. Conduction can take place in solids, liquids, or gases.In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion.In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons. The rate of heat conduction through a medium depends on the geometry of the medium, its thickness, and the material of the medium, as well as the temperature difference across the medium.We know that wrapping a hot water tank with glass wool (an insulating material) reduces the rate of heat loss from the tank. The thicker the insulation, the smaller the heat loss.We also know that a hot water tank will lose heat at a higher rate when the temperature of the room housing the tank is lowered. Further, the larger the tank, the larger the surface area and thus the rate of heat loss.Heat conduction through the large plain wallConsider steady heat conduction through a large plane wall of thickness Δx = L and area A, as shown in the figure. The temperature difference across the wall is ΔT = T2-T1The rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area but is inversely proportional to the thickness of the layer. That is,Rate of heat conduction ∝ (Area) (Temperature Difference) / Thickness Fourier's law of heat conductionFourier's law of conduction of heat is expressed asQ ∝ A × (dt / dx)Where, Q = heat flow through a body per unit time (in watts W) A = Surface area of heat flow m2, dt = Temperature difference in oC or K dx = Thickness of the body in the direction of flow, m.Hence, we can express the Heat Conduction formula byQ = – k × A (dt / dx)Wherek = thermal conductivity of the body and it is a Constant of proportionalityHeat is conducted in the direction of decreasing temperature, and the temperature gradient becomes negative when temperature decreases with increasing x. The negative sign in Eq. ensures that heat transfer in the positive x-direction is a positive quantity.Factors affecting the conduction of heat:-i)The cross-sectional area of the rod (A) ii)The temperature difference between the two surfaces of the conductor (θ1- θ2) iii) Time for which heat flows. (t) iv)Distance between two surfaces. (d)Applications of conduction-1. Fins provided on a motorcycle engine 2. Electric fuse cut off 3. Electric heater 4. Carbonization of coal 5. Melting of iron in a blast furnace 6. Fission reactions in nuclear fuel rods of nuclear reactors. 7. Electrical wiring in housing 8. Electric discharge machining in manufacturingTypical units of measure for conductive heat transfer are:Per unit area (for a given thickness)Metric (SI): Watt per square meter (W/m)Metric (SI) : Watt (W) or kilowatts (kW)The thermal conductivity of a material can be defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference.The thermal conductivity of a material is a measure of the ability of the material to conduct heat.A high value for thermal conductivity indicates that the material is a good heat conductor, and a low value indicates that the material is a poor heat conductor or insulator.Note that materials such as copper and silver that are good electrical conductors are also good heat conductors, and have high values of thermal conductivity.Materials such as rubber, wood, and styrofoam are poor conductors of heat and have low conductivity values.Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion.The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, but it also complicates the determination of heat transfer rates.Consider the cooling of a hot block by blowing cool air over its top surface (Figure).heat transfer by convectionFor example, in the absence of a fan, heat transfer from the surface of the hot block in the figure will be by natural convection since any motion in the air, in this case, will be due to the rise of the warmer (and thus lighter) air near the surface and the fall of the cooler (and thus heavier) air to fill its place.Heat transfer between the block and the surrounding air will be by conduction if the temperature difference between the air and the block is not large enough to overcome the resistance of air to movement and thus to initiate natural convection currents.Energy is first transferred to the air layer adjacent to the block by conduction.This energy is then carried away from the surface by convection, that is, by the combined effects of conduction within the air that are due to the random motion of air molecules and the bulk or macroscopic motion of the air that removes the heated air near the surface and replaces it by the cooler air.Forced Convection- Convection is called forced convection if the fluid is forced to flow over the surface by external means such as a fan, pump, or the wind.Natural or Free Convection- In contrast, convection is called natural (or free) convection if the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid (Figure)forced and free convectionThe rate of convection heat transfer is observed to be proportional to the temperature difference, and is conveniently expressed by Newton's law of cooling as,h is the convection heat transfer coefficient in W/m^2 °C.A is the surface area through which convection heat transfer takes place.Ts is the surface temperatureT∞ is the temperature of the fluid sufficiently far from the surface.The convection heat transfer coefficient h is not a property of the fluid. It is an experimentally determined parameter whose value depends on all the variables influencing convection such as the surface geometry, the nature of fluid motion, the properties of the fluid, and the bulk fluid velocity.Metric (SI) : Watt (W) or kilowatts (kW)1. Forced Convection is used to cool down the headed plate. 2. Forced Convection is used to cool down the heated engine of the vehicle. 3. Forced convection is used to cool down the laptop and supercomputer etc. 4. Forced convection is used to cool down the human body in the summer season. 5. Radiator – Puts warm air out at the top and draws in cooler air at the bottom.Comparison between conduction and convection are as follows ; Sr. no. Conduction Convection1.It is the mode of heat transfer from one part of substance to another part of same substance or one substance to another without displacement of molecules or due to the vibrations of molecules.It is the mode of heat transfer from one part of a substance to another part of same substance or one substance to another with a displacement of molecules or due to the fluid flowing.2.It is the mode of heat transfer in which fluid particles do not mix with each other.It is the mode of heat transfer in which fluid particles mix with each other.3.It occurs in solid.It occurs in liquid and gases.4.It governs by Fourier"s law of heat conduction.It governs by Newton"s law of convection heat transfer.5.Example: Heat flow from one end to other end of metal rod.Example: Heat flow from boiler shell to water. Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.Unlike conduction and convection, the transfer of energy by radiation does not require the presence of an intervening medium. In fact, energy transfer by radiation is the fastest (at the speed of light) and it suffers no attenuation in a vacuum. This is how the energy of the sun reaches the earth.three modes of energy transfer1.Conversion of thermal energy of the hot source into electromagnetic waves:All bodies above absolute zero temperature are capable of emitting radiant energy. The energy released by a radiating surface is not continuous but is in the form of successive and separate (discrete) packets or quanta of energy called photons. The photons are propagated through space as rays; the movement of a swarm of photons is described as electromagnetic waves.2. Passage of wave motion through intervening space:The photons, as carries of energy, travel with unchanged frequency in straight paths with speed equal to that of light.3. Transformation of waves into heat:When the photons approach the cold receiving surface, there occurs reconversion of wave motion into thermal energy which is partly absorbed, reflected, or transmitted through the receiving surface.In heat transfer studies we are interested in thermal radiation, which is the form of radiation emitted by bodies because of their temperature. It differs from other forms of electromagnetic radiation such as x-rays, gamma rays, microwaves, radio waves, and television waves that are not related to temperature.Radiation Heat transfer equation :The net exchange of heat between the two radiating surfaces is due to the face that one at a higher temperature radiates more and receives less energy for its absorption.Q = σ ε Ai Fij (Ti^4 – Tj^4)Where,Q = Heat flow rate from surface i to j σ = Stephan- boltzman constant ε = Emmissivity Ai = area of surface i Fij = Form factor between surface i and j Ti and Tj = absolute temperatures of the surfacesThe maximum rate of radiation that can be emitted from a surface at an absolute temperature (in K) is given by the Stefan–Boltzmann law asEb = σb AT^4Where Eb is the energy radiated by the black body, σb is the Stefan Boltzman constantStefan Boltzman constantIt is the fraction of energy that is transmitted through the body. Or The ratio of the amount of energy transmitted to the amount of energy incident on a body.Black body: A black body is an object that absorbs all the radiant energy reaching its surface from all the directions with all the wavelengths. Grey Body: A gray body is defined as a body whose absorptivity of a surface does not vary with variation in temperature and wavelength of the incident radiation. It absorbs a definite percentage of incident energy irrespective of wavelength. Its absorptivity lies between 0 to 1.Reflectivity: It is defined as the ratio of the amount of energy reflected in the amount of energy incident on a body.Typical units of measure for the rate of radiant heat transferMetric (SI) ——Watt per square meter (W/mExample of radiation: Energy emitted by the sun reaches the earth through radiation.1) Fins provided on the motorcycle engine. 2) Cooling jackets provided in cylinder blocks 3) Radiator 4) Heat carried away by exhaust gases 5) Heat transfer from sun rays into the cabin/car 6) HVAC system etc. link to Top Branches of Mechanical Engineering link to Shree Ram Ayodhya Murti, idol - Vector , Wallart

Conduction heat transfer is the transfer of thermal energy by interactions between adjacent atoms and molecules of a solid. Conduction Conduction involves the transfer of heat by the interaction between adjacent molecules of a material. Heat transfer by conduction is dependent upon the driving "force" of temperature difference and the resistance to heat transfer. The resistance to heat transfer is dependent upon the nature and dimensions of the heat transfer medium. All heat transfer problems involve the temperature difference, the geometry, and the physical properties of the object being studied. In conduction heat transfer problems, the object being studied is usually a solid. Convection problems involve a fluid medium. Radiation heat transfer problems involve either solid or fluid surfaces, separated by a gas, vapor, or vacuum. There are several ways to correlate the geometry, physical properties, and temperature difference of an object with the rate of heat transfer through the object. In conduction heat transfer, the most common means of correlation is through Fourier's Law of Conduction. The law, in its equation form, is used most often in its rectangular or cylindrical form (pipes and cylinders), both of which are presented below. Rectangular $$ \dot{Q} = k ~A \left({ \Delta T \over \Delta x }\right) $$ Cylindrical $$ \dot{Q} = k ~A \left({ \Delta T \over \Delta r }\right) $$ where: \(\dot{Q} \) = rate of heat transfer (Btu/hr) A = cross-sectional area of heat transfer (ft2) Δx = thickness of slab (ft) Δr = thickness of cylindrical wall (ft) ΔT = temperature difference (°F) k = thermal conductivity of slab (Btu/ft-hr-°F) The use of Equations 2-4 and 2-5 in determining the amount of heat transferred by conduction is demonstrated in the following examples. Conduction-Rectangular Coordinates Example: 1000 Btu/hr is conducted through a section of insulating material shown in Figure 1 that measures 1 ft2 in cross-sectional area. The thickness is 1 in. and the thermal conductivity is 0.12 Btu/hr-ft-°F. Compute the temperature difference across the material. Figure 1: Conduction Through a Slab Solution: Using Equation 2-4: $$ \dot{Q} = k ~A \left({ \Delta T \over \Delta x }\right) $$ Solving for ΔT: $$ \begin{eqnarray} \Delta T &=& \dot{Q} \left({ \Delta x \over k ~A }\right) onumber \\ &=& { \left({ 1000 ~{\text{Btu} \over \text{hr}} }\right) \left({1 \over 12} ~\text{ft}\right) \over \left({ 0.12 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} }\right) (1 ~\text{ft}^2) } onumber \\ \Delta T &=& 694^{\circ}F \end{eqnarray} $$ Example: A concrete floor with a conductivity of 0.8 Btu/hr-ft-°F measures 30 ft by 40 ft with a thickness of 4 inches. The floor has a surface temperature of 70°F and the temperature beneath it is 60°F. What is the heat flux and the heat transfer rate through the floor? Solution: Using Equations 2-1 and 2-4: $$ \begin{eqnarray} \dot{Q}'' &=& { \dot{Q} \over A } = k \left({ \Delta T \over \Delta x }\right) onumber \\ &=& \left({ 0.8 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} }\right) \left({ 10^{\circ}\text{F} \over 0.333 ~\text{ft} }\right) onumber \\ &=& 24 ~{ \text{Btu} \over \text{hr-ft}^2 } \end{eqnarray} $$ Using Equation 2-3: $$ \begin{eqnarray} \dot{Q} &=& k ~A \left({ \Delta T \over \Delta x }\right) = \dot{Q}'' A onumber \\ &=& \left(24 ~{ \text{Btu} \over \text{hr-ft}^2 }\right) (1200 ~\text{ft}^2) onumber \\ &=& 28,800 ~{\text{Btu} \over \text{hr}} \end{eqnarray} $$ Equivalent Resistance Method It is possible to compare heat transfer to current flow in electrical circuits. The heat transfer rate may be considered as a current flow and the combination of thermal conductivity, thickness of material, and area as a resistance to this flow. The temperature difference is the potential or driving function for the heat flow, resulting in the Fourier equation being written in a form similar to Ohm's Law of Electrical Circuit Theory. If the thermal resistance term Δx/k is written as a resistance term where the resistance is the reciprocal of the thermal conductivity divided by the thickness of the material, the result is the conduction equation being analogous to electrical systems or networks. The electrical analogy may be used to solve complex problems involving both series and parallel thermal resistances. The student is referred to Figure 2, showing the equivalent resistance circuit. A typical conduction problem in its analogous electrical form is given in the following example, where the "electrical" Fourier equation may be written as follows. $$ \dot{Q}'' = { \Delta T \over R_{th} } $$ where: \(\dot{Q}'' \) = Heat Flux (\(\dot{Q}/A \)) (Btu/hr-ft2) ΔT = Temperature Difference (°F) Rth = Thermal Resistance (Δx/k) (hr-ft2-°F/Btu) Figure 2: Equivalent Resistance Electrical Analogy Example: A composite protective wall is formed of a 1 in. copper plate, a 1/8 in. layer of asbestos, and a 2 in. layer of fiberglass. The thermal conductivities of the materials in units of Btu/hr-ft-°F are as follows: kCu = 240, kasb = 0.048, and kfib = 0.022. The overall temperature difference across the wall is 500°F. Calculate the thermal resistance of each layer of the wall and the heat transfer rate per unit area (heat flux) through the composite structure. Solution: $$ \begin{eqnarray} R_{Cu} &=& { \Delta x_{Cu} \over k_{Cu} } onumber \\ &=& { 1 ~\text{in} \left({ 1 ~\text{ft} \over 12 ~\text{in} }\right) \over 240 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} } onumber \\ &=& 0.000347 ~{\text{hr-ft}^2\text{-}^{\circ}\text{F} \over \text{Btu}} \end{eqnarray} $$ $$ \begin{eqnarray} R_{asb} &=& { \Delta x_{asb} \over k_{asb} } onumber \\ &=& { 0.125 ~\text{in} \left({ 1 ~\text{ft} \over 12 ~\text{in} }\right) \over 0.048 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} } onumber \\ &=& 0.2170 ~{\text{hr-ft}^2\text{-}^{\circ}\text{F} \over \text{Btu}} \end{eqnarray} $$ $$ \begin{eqnarray} R_{fib} &=& { \Delta x_{fib} \over k_{fib} } onumber \\ &=& { 2 ~\text{in} \left({ 1 ~\text{ft} \over 12 ~\text{in} }\right) \over 0.022 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} } onumber \\ &=& 7.5758 ~{\text{hr-ft}^2\text{-}^{\circ}\text{F} \over \text{Btu}} \end{eqnarray} $$ $$ \begin{eqnarray} { \dot{Q} \over A } &=& { (T_i - T_o) \over (R_{Cu} + R_{asb} + R_{fib}) } onumber \\ &=& { 500^{\circ}\text{F} \over (0.000347 0.2170 + 7.5758) ~{\text{hr-ft}^2\text{-}^{\circ}\text{F} \over \text{Btu}} } onumber \\ &=& 64.2 ~{\text{Btu} \over \text{hr-ft}^2} \end{eqnarray} $$ Conduction-Cylindrical Coordinates Heat transfer across a rectangular solid is the most direct application of Fourier's law. Heat transfer across a pipe or heat exchanger tube wall is more complicated to evaluate. Across a cylindrical wall, the heat transfer surface area is continually increasing or decreasing. Figure 3 is a cross-sectional view of a pipe constructed of a homogeneous material. Figure 3: Cross-sectional Surface Area of a Cylindrical Pipe The surface area (A) for transferring heat through the pipe (neglecting the pipe ends) is directly proportional to the radius (r) of the pipe and the length (L) of the pipe. As the radius increases from the inner wall to the outer wall, the heat transfer area increases. The development of an equation evaluating heat transfer through an object with cylindrical geometry begins with Fourier's law Equation 2-5. $$ \dot{Q} = k ~A \left({ \Delta T \over \Delta r }\right) $$ From the discussion above, it is seen that no simple expression for area is accurate. Neither the area of the inner surface nor the area of the outer surface alone can be used in the equation. For a problem involving cylindrical geometry, it is necessary to define a log mean cross-sectional area (Alm). $$ A_{lm} = { A_{outer} - A_{inner} \over \ln \left({ A_{outer} \over A_{inner} }\right) } $$ Substituting the expression 2πrL for area in Equation 2-7 allows the log mean area to be calculated from the inner and outer radius without first calculating the inner and outer area. $$ \begin{eqnarray} A_{lm} &=& { 2 \pi ~r_{outer} L - 2 \pi ~r_{inner} L \over \ln \left({ 2 \pi ~r_{outer} L \over 2 \pi ~r_{inner} L }\right) } onumber \\ &=& 2 \pi ~L \left({ r_{outer} - r_{inner} \over \ln{ r_{outer} \over r_{inner} } }\right) \end{eqnarray} $$ This expression for log mean area can be inserted into Equation 2-5, allowing us to calculate the heat transfer rate for cylindrical geometries. $$ \begin{eqnarray} \dot{Q} &=& k ~A_{lm} \left({ \Delta T \over \Delta r }\right) onumber \\ &=& k \left[2 \pi ~L \left({ r_o - r_i \over \ln{ r_o \over r_i } }\right) \right] \left({ T_o - T_i \over r_o - r_i }\right) onumber \\ \dot{Q} &=& { 2 \pi ~k ~L ~(\Delta T) \over \ln (r_o / r_i) } \end{eqnarray} $$ where: L = length of pipe (ft) ri = inside pipe radius (ft) ro = outside pipe radius (ft) Example: A stainless steel pipe with a length of 35 ft has an inner diameter of 0.92 ft and an outer diameter of 1.08 ft. The temperature of the inner surface of the pipe is 122°F and the temperature of the outer surface is 118°F. The thermal conductivity of the stainless steel is 108 Btu/hr-ft-°F. Calculate the heat transfer rate through the pipe. Calculate the heat flux at the outer surface of the pipe. Solution: $$ \begin{eqnarray} \dot{Q} &=& { 2 \pi ~k ~L ~(T_h - T_c) \over \ln (r_o / r_i) } onumber \\ &=& { 6.28 \left(108 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} \right) (35 ~\text{ft}) (122^{\circ}\text{F} - 118^{\circ}\text{F}) \over \ln { 0.54 ~\text{ft} \over 0.46 ~\text{ft} } } onumber \\ &=& 5.92 \times 10^5 ~{ \text{Btu} \over \text{hr} } \end{eqnarray} $$ $$ \begin{eqnarray} \dot{Q}'' &=& { \dot{Q} \over A } onumber \\ &=& { \dot{Q} \over 2 \pi ~r_o ~L } onumber \\ &=& { 5.92 \times 10^5 ~{ \text{Btu} \over \text{hr} } \over 2 (3.14) (0.54 ~\text{ft}) (35 ~\text{ft}) } onumber \\ &=& 4985 ~{ \text{Btu} \over \text{hr-ft}^2 } \end{eqnarray} $$ Example: A 10 ft length of pipe with an inner radius of 1 in and an outer radius of 1.25 in has an outer surface temperature of 250°F. The heat transfer rate is 30,000 Btu/hr. Find the interior surface temperature. Assume k = 25 Btu/hr-ft-°F. Solution: $$ \dot{Q} = { 2 \pi ~k ~L ~(T_h - T_c) \over \ln (r_o / r_i) } $$ Solving for Th: $$ \begin{eqnarray} T_h &=& { \dot{Q} ~\ln (r_o / r_i) \over 2 \pi ~k ~L } + T_c onumber \\ &=& { \left(30,000 ~{ \text{Btu} \over \text{hr} } \right) \left(\ln { 1.25 ~\text{in} \over 1 ~\text{in} } \right) \over 2 (3.14) \left(25 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} \right) (10 ~\text{ft}) } + 250^{\circ}\text{F} onumber \\ &=& 254^{\circ}\text{F} \end{eqnarray} $$ The evaluation of heat transfer through a cylindrical wall can be extended to include a composite body composed of several concentric, cylindrical layers, as shown in Figure 4. Figure 4: Composite Cylindrical Layers Example: A thick-walled nuclear coolant pipe (ks = 12.5 Btu/hr-ft-°F) with 10 in. inside diameter (ID) and 12 in. outside diameter (OD) is covered with a 3 in. layer of asbestos insulation (ka = 0.14 Btu/hr-ft-°F) as shown in Figure 5. If the inside wall temperature of the pipe is maintained at 550°F, calculate the heat loss per foot of length. The outside temperature is 100°F. Figure 5: Pipe Insulation Problem Solution: $$ \begin{eqnarray} { \dot{Q} \over L } &=& { 2 \pi ~(T_{in} - T_o) \over \left[{ \ln (r_2 / r_1) \over k_s } + { \ln (r_3 / r_2) \over k_a } \right] } onumber \\ &=& { 2 \pi ~(550^{\circ}\text{F} - 100^{\circ}\text{F}) \over \left[{ \ln \left({ 6 ~\text{in} \over 5 ~\text{in} }\right) \over 12.5 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} } + { \ln \left({ 9 ~\text{in} \over 6 ~\text{in} }\right) \over 0.14 ~{\text{Btu} \over \text{hr-ft-}^{\circ}\text{F}} } \right] } onumber \\ &=& 971 ~{ \text{Btu} \over \text{hr-ft} } \end{eqnarray} $$ Thermal conduction is the flow of thermal energy (heat) from higher to lower temperatures through molecular vibrations and collisions. Conduction occurs within an object or from a hot object to a cold object in contact with the former. It can occur in solids, liquids, and gases but is primarily observed in solids where molecules are closely packed. Heat will continue to flow until thermal equilibrium is reached. Conduction Warming hands by touching a hot bodyHeating one end of a metal rodHeating a frying pan on top of a stoveHot air immediately above the Earth's surface How is Heat Transferred Through Thermal Conduction According to kinetic theory, matter is made of particles that are in constant random motion. This motion manifests as thermal energy, which depends on the temperature. The higher the temperature, the higher the thermal energy. The motion of particles, whether translatory or vibrational, leads to collisions. The particles transfer energy among themselves. Consequently, heat travels from a high-temperature region to a low-temperature region. For thermal conduction to occur, there has to be a temperature gradient. Fourier's law of thermal conduction states that the time rate of heat transfer through a material is proportional to the negative temperature gradient and the area through which the heat flows at right angles to that gradient. Mathematically, Fourier's law can be written as \[Q = – K A \frac{\Delta T}{\Delta x} \] Where Q: Heat transfer rate (Js-1 or W) K: Thermal conductivity (Wm-1K-1) A: Cross-sectional area (m2) \(\frac{\Delta T}{\Delta x} \): Temperature gradient (Km-1) Suppose heat flows through a conductor of thickness d whose ends are at temperatures TA (hot) and TB (cold). The heat flowing per second through the conductor is \[Q = KA\frac{T_B – T_A}{d} \] Heat Conduction Equation Thermal conductivity is a physical property of substances. In the above equation, suppose A = 1, d = 1, and (TA – TB) = 1. Then K = Q Thus, thermal conductivity is defined as the amount of heat flowing through a conductor of unit length, whose cross-section has a unit area and whose ends are at a unit temperature difference. Metals have high thermal conductivity because their valence electrons are delocalized and can efficiently conduct heat. For example, the thermal conductivities of silver and copper are 406 Wm-1K-1 and 385 Wm-1K-1, respectively. Insulators are poor conductors of heat. They have voids in between the atoms, which interfere with heat transfer. For example, the thermal conductivity of wood ranges from 0.04 to 0.12 Wm-1K-1. Air is a poor conductor of heat. Its thermal conductivity at 0 ˚C is 0.024 Wm-1K-1. Article was last reviewed on Monday, January 2, 2023