Dec. 29, 1936. E. RICE, JR 2,065,984

REFRIGERATION

Original Filed July 7, 1933 3 Sheets-Sheet 1

Fig. 1.

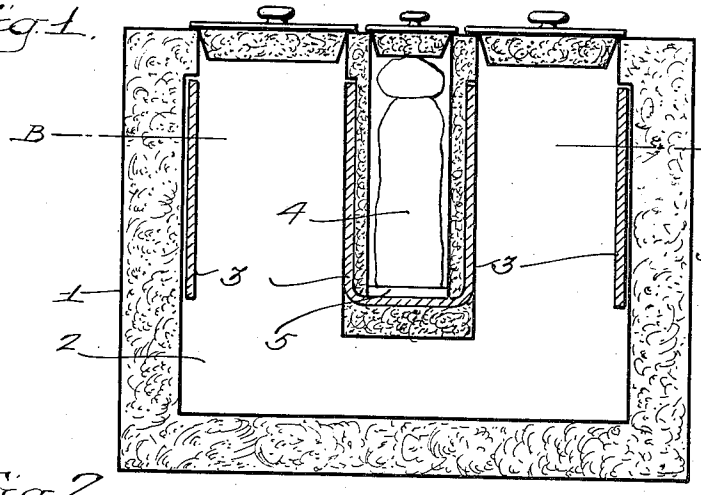


Fig. 3.

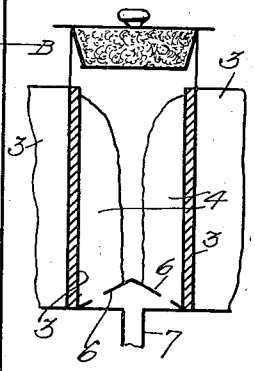


Fig. 2.

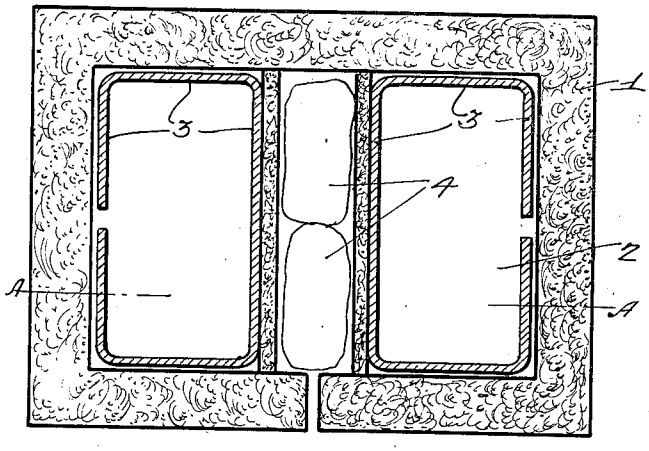


Fig. 11

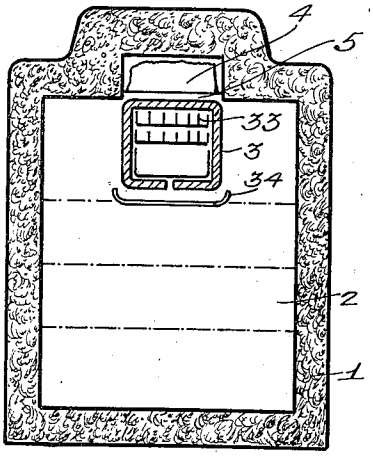
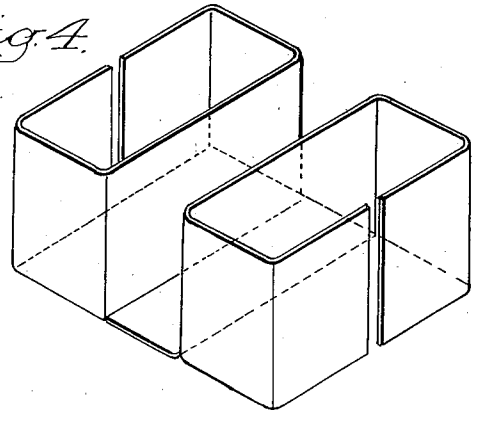


Fig. 4.



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Dec. 29, 1936. E. RICE, JR 2,065,984

REFRIGERATION

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Fig. 5.

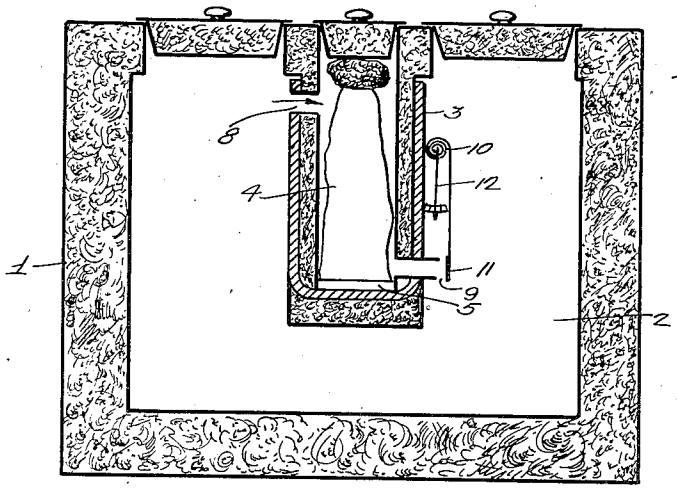


Fig. 7

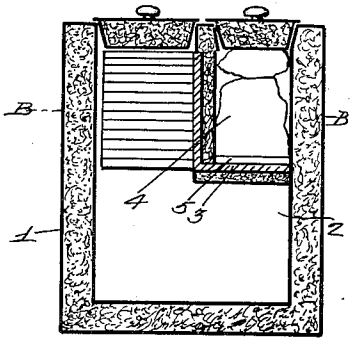


Fig 8.

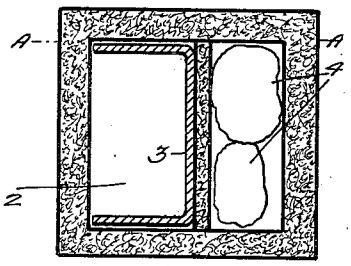


Fig. 6

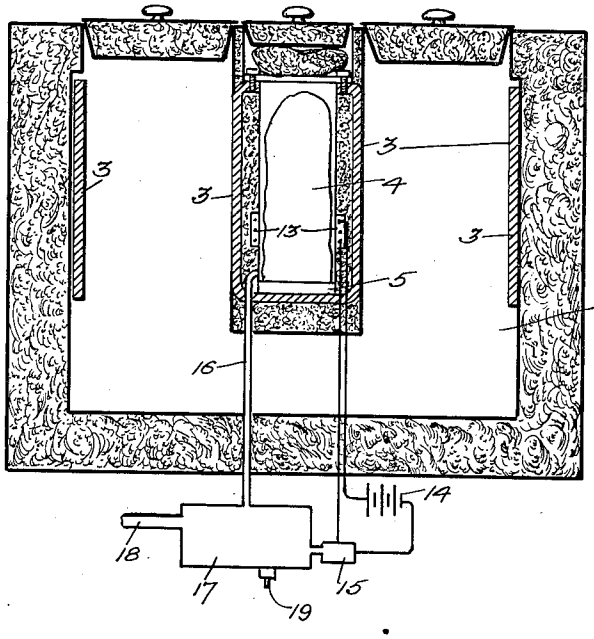


Fig. 9.

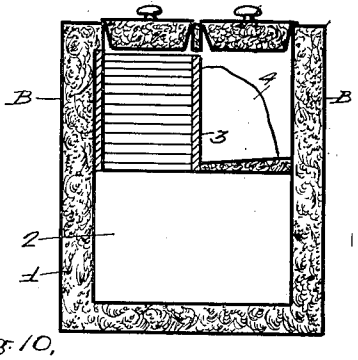
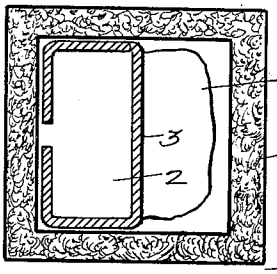


Fig. 10.



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REFRIGERATION

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Fig. 12

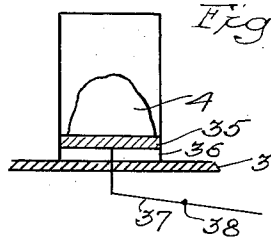


Fig. 17

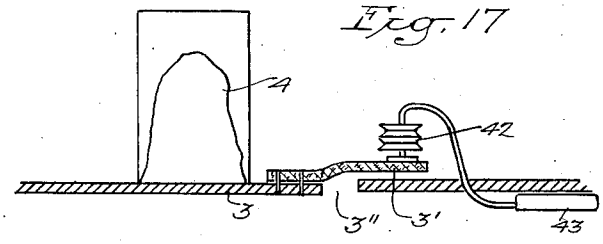


Fig. 13

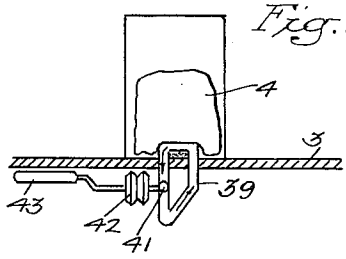


Fig. 18

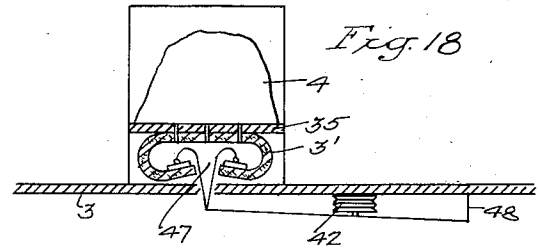


Fig. 14

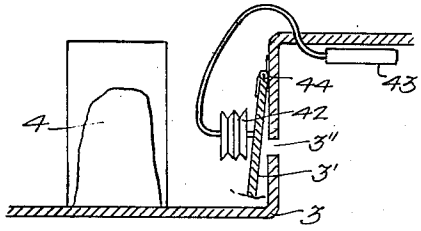


Fig. 19

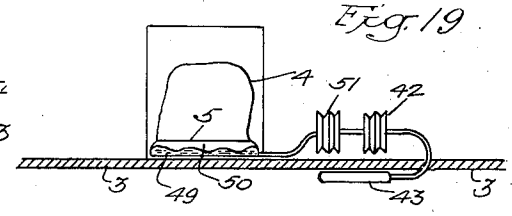


Fig. 20

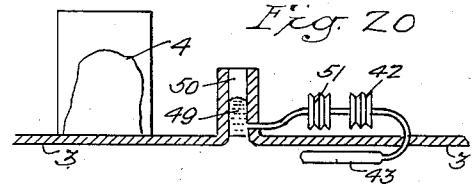


Fig. 15

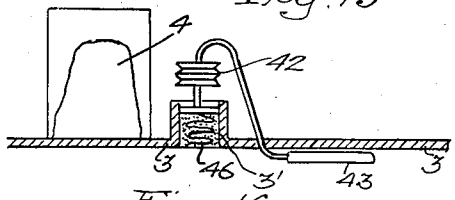


Fig. 16

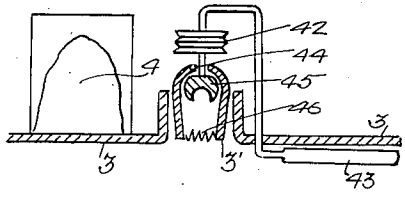
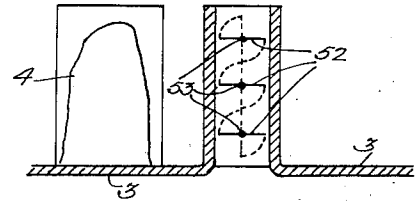


Fig. 21



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Patented Dec. 29, 1936 2,065,984

UNITED STATES PATENT OFFICE

2,065,984

REFRIGERATION

Edward Rice, Jr., Croton-on-Hudson, N. Y., assignor to International Carbonic, Inc., Wilmington, Del., a corporation of Delaware

Original application July 7, 1933, Serial No. 679,435. Divided and this application November 3, 1934, Serial No. 751,391

2 Claims. (Cl. 62—91.5)

This invention relates to improvements in refrigerating methods and apparatus for use with solid refrigerants, such as solid carbon dioxide, water ice, brine ice, etc.

The invention described and claimed herein resides in a novel way of forming and using a solid metallic heat conductor for transferring heat from a refrigerated area or material to a solid refrigerant; wherein the said conductor consists of a continuous thick sheet or plate of a good heat-conducting metal so bent or otherwise formed that vertical portions of the conductor provide large extended heat-absorbing surfaces directly exposed to the refrigerated space or material and located above the bottom of the refrigerated space, while an immediately adjoining portion of the conductor presents in the refrigerator-containing space comparatively smaller surfaces for heat transfer directly to the solid refrigerant. This novel construction of the conductor makes it possible to build refrigerating apparatus, such as ice cream cabinets, wherein the ice bunker projects into the refrigerated space and ready access both to the refrigerated space and to the ice bunker can be provided from above; and wherein the constant metallic heat-absorbing surfaces extend vertically from the bottom level of the bunker toward the top of the refrigerated space and tend to equalize the cabinet temperatures and protect the materials stored near the top. The invention also makes it possible to locate the extended vertical heat-absorbing surfaces of the conductor plate in the upper warmest part of a household refrigerator and at the same time provide an ice bunker located above the refrigerated space wherein the portion of the conductor, immediately adjacent to the heat-absorbing portions, which transmits heat to the refrigerant forms the bottom of the bunker. In this case, the vertical heat-absorbing portions of the conductor extend downwardly from the bottom of the bunker; while in the ice cream cabinet type of apparatus the vertical portions extend upwardly from the bottom level of the bunker. The novel way of forming the metallic heat conductor claimed in this application permits the use of a much less costly conductor than heretofore used; and at the same time permits placing the metallic heat-absorbing surfaces in the most efficient location in the refrigerated space. The general type of heat conductor shown herein corresponds to the general type, that having the extended heat-absorbing surfaces formed of a continuous metal sheet or plate, shown in the parent case of my application Serial Number 679,435 filed July 7, 1933, now matured into Patent No. 1,980,089, issued Nov. 6, 1934, of which the present application is a division. The parent application claims such a conductor where the extended heat-absorbing surfaces are in the form of a substantially horizontal overhead plate; while the present application claims the conductor in a form suitable for other forms of refrigerating apparatus wherein the extended heat-absorbing surfaces are substantially vertical and located above the bottom of, but within, the refrigerated space.

An object of the invention is to provide a means for transferring heat to a solid refrigerant at a higher rate than provided in previously known methods, the refrigerant being used in the usual and ordinary processes of refrigerated storage and transportation of perishable foodstuffs.

Another object is to provide a means for transferring heat to small quantities of a solid refrigerant at the same rate as to comparatively large quantities, the refrigerant being used in the usual and ordinary processes of refrigerated storage and transportation of perishable foodstuffs with the result that approximately constant refrigerating temperatures can be maintained substantially as long as any of the refrigerant remains.

Another object is to provide a means for transferring heat to small quantities of a solid refrigerant at the same rate as to comparatively large quantities, the refrigerant being used for cooling a fluid such as air or water, thus making it possible to use smaller quantities of the refrigerant than heretofore for a desired rate of heat transfer and to maintain the same rate of heat transfer substantially as long as any of the refrigerant remains.

Another object is to provide a means for maintaining substantially constant temperatures in the refrigeration of perishable foodstuffs within a range of approximately 0° F. to 50° F. when using solid refrigerants, such as solid CO_2 or brine ice of a considerably lower temperature than that required in the refrigerating process.

More specifically an object is to provide a solid metallic heat conductor between the area or mass to be refrigerated and the solid refrigerant with sufficient surface in a uniform or controlled heat exchange relation with the refrigerant, with sufficient surface in heat exchange relation with the refrigerated area or mass, and with sufficient heat transfer capacity or cross section to

pick up and transfer to the refrigerant the maximum amount of heat as required to effect the desired refrigeration.

More specifically an object is to provide a solid metallic heat conductor of the above characteristics for use with low temperature solid refrigerants, such as solid CO_2 and brine ice, in combination with means for controlling and regulating—(A) The heat transfer to the conductor from the refrigerated area (B) The heat transfer from the conductor to the refrigerant (C) The heat transfer along the conductor—or a combination of these means—for the purpose of regulating the temperature of the refrigerated area.

Another specific object is to provide a solid metallic heat conductor of the above characteristics which is commercially practicable in refrigerated storage and transportation of perishable foodstuffs, and which can be constructed of cheap available metals such as aluminum or copper; which can be easily made of bent or welded plates or cast or extruded forms of such metals; and which provides the necessary heat-absorbing and heat-emitting surfaces and heat transfer capacities without interfering with the usual and ordinary practices in construction of refrigerated storage and transportation units using solid refrigerants, such as household refrigerators, ice cream cabinets, motor truck bodies, R/R cars and containers, etc.

Figure 1 is a vertical section of an ice cream cabinet embodying my invention; Fig. 2 being a plan view on B—B of Fig. 1;

Fig. 3 illustrates a vertical section through the bunker of a cabinet wherein the conductor is arranged for use with brine ice;

Fig. 4 is a perspective view of the metallic conductor incorporated in Fig. 1;

Figs. 5 to 10, inclusive, are sectional views of other embodiments of my invention in ice cream cabinets;

Fig. 11 shows the invention as applied to a household refrigerator, and

Figs. 12 to 21, inclusive, are respectively diagrammatic fragmentary sectional views illustrating other modifications within the scope of my invention.

During the past two summers I have designed and had constructed and commercially used a variety of improved forms of refrigerating apparatus for the storage and transportation of perishable foods, ice cream etc. which employ as the source of refrigeration solid refrigerants such as solid carbon dioxide, water ice, or brine ice in combination with an extended solid metallic heat conductor which is chilled either by direct contact with the solid refrigerant or by some other uniform or controlled heat exhange relationship with the refrigerant.

The characteristics of this metallic heat conductor must be such that (*a*) it forms a principal path of heat transfer between the refrigerated area or mass and the solid refrigerant—(*b*) it has a surface area in suitable heat exchange relationship with the space or mass refrigerated, this surface area being sufficiently extended to provide the number of square feet of heat-absorbing surface required to absorb the heat removed from the refrigerated area, at the temperature differential ranges used in any given apparatus between the conductor surface and the refrigerated area—(*c*) that it has a minimum cross sectional mass at any particular point sufficient to conduct in the direction of the solid refrigerant the heat absorbed by the surface extended beyond that point, at the temperature differential ranges used in any given apparatus between the heat-absorbing conductor surfaces and the conductor surfaces exposed to the solid refrigerant—(*d*) it has a surface area in suitable heat exchange relationship with the solid refrigerant, this surface always being smaller than the surface exposed to and absorbing heat from the refrigerated area.

This general method of using solid refrigerants is fully disclosed and claimed in my pending application Serial Number 467,999, filed July 14, 1930, and various forms of apparatus for carrying out the method are there described. In this application I wish to disclose more specifically the principles of this method of refrigeration, to describe in more detail the characteristics of the solid metallic heat conductor which is the essence and concrete embodiment of the invention, and to claim improved forms of the conductor and ways of using it.

The use of this metallic conductor conforms to the usual and well known principles of heat absorption and emission by, and transfer through, a solid homogeneous material. For instance a certain number of heat units per hour are to be absorbed to maintain the required temperature in a household refrigerator, say equal to the meltage of one pound of water ice per hour. In using water ice for this purpose which melts at 32° F. a metallic conductor of copper or aluminum can be chilled to an average temperature say of 36° to 44° F. by direct contact with a surface of the ice. This conductor can in turn chill the air of the refrigerator to say an average of 47° F. in an 80° room. To accomplish this approximately 144 B. t. u.'s per hour must be transferred from the air of the refrigerator to the ice, or sufficient to melt one pound of ice per hour. Where air circulates by natural convection over a cooling surface under these conditions, approximately 1½ B. t. u.'s per hour per degree F. differential between the air and the cooling surface, per square foot of cooling surface can be absorbed. Therefore, about fifteen square feet of chilled conductor surface is exposed to the air at an average temperature of 40° F., thus absorbing approximately 15 sq. ft. × 1½ B. t. u.'s per hour × 7° F. differential—157 B. t. u.'s per hour—this meets condition (*b*) above. Next a surface area of the conductor must be in direct contact (in the present instance) with the ice. This surface need be only a fraction of the surface absorbing heat from the air; and in this fact lies the great practical advantage in this method of refrigeration, as well as one of the principal objects of the invention, as it permits satisfactory refrigeration with small amounts of solid refrigerant. There is no exact physical data covering this heat transfer from the metal to a solid refrigerant but experimental observation shows that it is from fifty to several hundred times as much per unit area per degree difference in temperature as from the air to the conductor surface. For instance, with a sufficiently thick conductor, say ⅜" of aluminum, fifteen square inches of water ice contact with the conductor can absorb the heat that is picked up from the air by fifteen square of conductor surface exposed to convection currents in the form of fins—this corresponds to condition (*d*) above.

With a given surface exposed to the air and a certain amount of ice available for minimum contact with the conductor then condition (*c*) above becomes an absolutely essential consideration in constructing a conductor for use in this

method of refrigeration. After means are provided to get the heat into the metal conductor, by providing a necessary area of chilled surface, and to get the heat out of the conductor to the solid refrigerant, by providing an area of the conductor in uniform or controlled heat exchange relationship with the refrigerant, it is necessary to make the conductor sufficiently thick to transfer the maximum amount of heat to be taken out of any given refrigerated space or mass to effect the desired refrigeration under the most adverse conditions of actual use. This thickness is determined for the minimum temperature differential that it is feasible to use between the points where the heat enters and leaves the conductor, or between any two points along the conductor path. The rate per hour for this form of heat transfer is established for all the available metals and can be easily ascertained in the usual physics handbooks. Briefly, for any given metal it varies directly as the cross section and temperature differential used. For instance, other features being equal, approximately twice as much heat will be transferred per hour by an aluminum plate ¼'' thick as by one ⅛'' thick for the same temperature differential; or approximately the same amount of heat will be transferred per hour by conductor plates, other factors being equal, made of ⅛'' copper, ¼'' aluminum, or ¾'' iron. It is to be expected that these rules can not be very reliable for overall temperature differentials of less than 2° or 3° F. or more than 20° to 30°; or for excessively long distances, say over 6 or 8 feet; or for excessively thin or thick conductors, say a conductive capacity of less than $\frac{1}{16}$'' of aluminum or over ½'' of copper. But the conductor can always be constructed with enough surface and sufficiently thick to take care of extreme conditions of use, and once constructed its heat transfer properties do not change. And experimental observation and wide commercial use show that—for the commonly available solid refrigerants, such as water ice, brine ice and solid CO_2; and for the cheaply available metals such as aluminum and copper, and to a lesser extent iron; and for ordinary commercial purposes in which it is common to use solid refrigerants, such as the transportation and storage of perishable foodstuffs—it is possible to construct refrigerating apparatus on the principles described above that is a great improvement over anything previously known in the art for use—with solid refrigerants.

In effect such apparatus provides a new means of transferring energy or power in the form of heat and greatly enlarges the entire field of use for solid refrigerants as a class, as well as providing a means of temperature control in the use of solid CO_2, often called "dry ice", the newly developed solid refrigerant which is now coming into such wide commercial use.

Heretofore the transfer of heat to solid refrigerants has been either—

From the air or other fluid or mass to be cooled directly to the surface of the ice. Here the inexorable law of physics, governing heat transfer from the fluid or mass to the ice on a square foot basis, and the steady reduction of volume and surface of a solid refrigerant when heat is applied, have made it inevitable that an excessive amount of the refrigerant had to be provided to supply sufficient surface to take up the required amounts of heat; and that there has been a steady rise in refrigerating temperatures due to the reduction in the heat absorbing surfaces of the refrigerant.

Or the heat transfer to the refrigerant has been through the walls of a refrigerant container or support in contact with the refrigerant, the heat reaching the ice at the area of contact—which in some cases provided a constant surface of the refrigerant itself direct for heat absorption, but which resulted in such small surfaces being available for that purpose that either very limited refrigeration was secured or such large containers had to be used as to be commercially impracticable. When necessary to segregate the ice metal containers were often used, usually of galvanized iron, but the function of the metal was altogether as a convenient material for constructing the containers and segregating the ice to control meltage, etc. and not as disclosed above to form an extended thick walled metal conductor of heat to the ice. The metal of the containers on which the ice rested acted to slow up heat transfer from the air to the refrigerant, not to facilitate it, and no heat in any useful amount was absorbed by the metal beyond the actual point of contact with the ice. The thinner the metal was in contact with the ice the more rapid the heat transfer; whereas in the extended metal conductor method described above the thicker the metal, the more rapid the transfer.

In constructing refrigerating apparatus for solid refrigerants using this solid metallic heat conductor it is not necessary that all the heat taken from the refrigerated space or mass be passed through the conductor, but only as stated in condition (a) above that it provide "a principal path of heat transfer"; although in usual practice most of the heat is thus transferred. It is sufficient that the fixed heat absorbing surface and transfer capacity provided by the conductor be large enough to take up the minimum amount of heat necessary to maintain a useful temperature when the volume of the refrigerant is considerably reduced—say to 5% or 10% of the bunker capacity. There will always be some heat get into the bunker space, and to the ice surface exposed there, through the walls of the bunker no matter how well insulated, and there may at times be some direct circulation of air from the refrigerated space, or around it, over the refrigerant as well as over the chilled conductor surfaces. In the absence of any regulation of the convection currents this would result in a somewhat quicker heat transfer when the bunker is well filled with ice; but this might even be useful sometimes—for instance in a transportation unit loaded with warm fruit when the refrigerant requirements are much heavier at first—or at other times it may do no harm to have a variation of say 5 degrees to 8 degrees F. from a full bunker down to 5% to 10% capacity. There must be always a substantial conductor with a heat absorbing surface extended away from contact with the ice, and a heat transfer capacity for keeping the maximum temperatures permissible. This additional partial circulation over the refrigerant of the convection currents of the refrigerated space can be controlled by means of thermostatically operated valves and thus become a temperature controlling feature when using solid CO_2. A smaller conductor would be used in this case, the valve shutting off the circulation over the refrigerant when fully iced or under conditions of minimum temperatures surrounding the refrigerating unit. Under maximum outside temperature conditions and as the

refrigerant volume is reduced the valve can open to permit the necessary additional heat transfer directly from the circulating air to the surface of the solid CO_2 thus maintaining approximately constant refrigerant temperatures.

This fact that all the heat need not pass through the conductor to obtain the benefits of this invention often permits a cheaper and easier construction. For instance, in the household refrigerant described above using water ice, a simple aluminum fin assembly placed vertically on one side of the ice compartment will provide 15 sq. ft. of constant heat absorbing surface, whereas 100 lb. block of water ice used in the ordinary way would present about 7½ sq. ft. of surface at first which would steadily diminish, reaching approximately 2½ sq. ft. at 25 lbs. If the conductor is loosely fitted with a 1 or 2 inch opening over the top then air can flow over the ice as well as the conductor. When first iced there would be 15 sq. ft. of conductor exposed for heat absorption plus 7½ sq. ft. of ice surface or a total of 22½ sq. ft. At 25 lb. of ice there would be 15 sq. ft. of conductor surface plus 2½ sq. ft. of ice surface or a total of 17½ sq. ft.—quite sufficient to maintain temperatures, which the 2½ sq. ft. surface of the 25 lbs. of ice alone cannot possibly do.

Besides being able to transfer heat to small amounts of solid refrigerants at a rate before unequalled in similar refrigerating apparatus, one of the principal advantages of this "conductor" method of using solid refrigerants is that it makes possible a controlled use of solid refrigerants such as solid CO_2 which sublimes at a temperature far below those required for ordinary refrigeration purposes, or such as a brine ice that can be made so as to melt from minus 6 degrees to about minus 30 degrees F. As explained above, the number of sq. ft. of heat absorbing conductor surface and the difference in temperature of this surface below that of the refrigerated space determines the amount of heat absorbed per hour—and thus the effective refrigerating temperatures. Obviously with a very cold refrigerant, like solid CO_2 at minus 110 degrees F., a small conductor surface could be chilled to a very low temperature and theoretically produce the same results as a much larger surface at a higher temperature. But in practice a difference in temperature of more than 8 or 10 degrees F. between the conductor surface and the air temperature of the refrigerated space does not result in a comparative increase in heat transfer from the air; and in most cases there is sufficient moisture in the air to cause considerable frosting of the low temperature surface which steadily cuts down heat transfer. Therefore, it is preferable to use as far as possible a large surface high temperature conductor with a low temperature refrigerant like solid CO_2.

This large surface chilled a few degrees below the ordinarily required refrigerating temperatures, which range between 0 degrees and 50 degrees F. can only be secured when using solid CO_2 as the refrigerant by means of some intermediate heat transfer agent such as a circulating gas or liquid, or such as a suitably formed good heat conducting metal. As mentioned above heat transfer to the refrigerant by a gas, including air, is not always satisfactory, and can not be maintained at a sufficiently high rate to the comparatively small surfaces of the refrigerant to meet most refrigerating means. Heat transfer by a circulating liquid such as alcohol or in freezing brine can transfer a considerable amount of heat to a small surface of the solid CO_2 especially when forced circulation is used, but as a principal means of heat transfer for refrigeration purposes such a system is not the subject of this application. A combination of circulating gas and liquid in the form of a condensible refrigerant such as methyl chloride, etc. can also be used as a heat transfer means, but that also is not the subject of this application. The only remaining convenient means for providing the required heat transfer agent is the use of a solid good heat conducting metal which can provide the necessary heat absorbing surface and transfer capacity, which can provide the necessary function of transferring heat at a comparatively high rate to a small surface of the refrigerant, and which permits of using means to control the rate of heat flow from the refrigerated area to the refrigerant via the conductor in order to regulate the temperature of the refrigerated area. Varous forms of such a solid metallic heat conductor for use with solid refrgerants such as solid CO_2 are included in the subject matter of this application, and various means, in combination with the conductor, for controlling the heat flow from the refrigerated area to the solid refrigerant via the conductor are included in the claims.

These various means, as indicated above, include:

(A) Ways for controlling the heat transfer from the refrigerated area to the conductor. When the refrigerated area consists of an enclosed space in which a fluid circulates by convection, such as air, water or a non-freezing liquid, and the conductor is of such a form that a wall can be set up to form a confined space in which the fluid can flow past the conductor, then a convenient way of control is to establish manually or thermostatically operated valves in this confined passage which restrict, or at times shut off entirely, the flow over the conductor as may be desired, thus limiting the amount of heat that has access to the conductor and so regulating the temperature of the refrigerated area. When it is impossible to set up this confined convection passage because of the nature of the refrigerated area, or when the character of the conductor permits, it is sometimes convenient to control the heat transfer to the conductor by placing predetermined amounts of insulation on the exposed surface of the conductor where it is extended away from contact with the refrigerant and does not form an integral part of the refrigerant containing bunker space.

(B) Ways for controlling the heat transfer from the conductor to the refrigerant. This forms probably the best method of controlling the temperature of the desirable large heat-absorbing conductor surface chilled only a few degrees below the refrigerated area, when using low temperature solid refrigerants like solid carbon dioxide. This method operates by controlling the spaced relation of the conductor and the solid refrigerant. When the ice is hard down on the bare conductor, a maximum heat flow results, and consequently the lowest refrigerating temperatures for a given apparatus. If the ice is held more than ¾'' from the conductor, there is not much effective heat transfer. However, from the point of contact to about ½'' away from the conductor provides a region where the surface of the solid CO_2 can be held in a controlled heat exchange relationship with the

conductor by which the temperature of the chilled conductor, and, therefore, the refrigerating temperatures, can be varied at will. The first break in the direct contact of the ice with the conductor will result in a marked resistance to the heat flow; and every change of a fraction of an inch toward or away from the conductor will speed up or retard the heat flow correspondingly. This action is in accordance with the ordinary physical laws of heat flow already referred to. Heat is accumulated by the conductor and brought by it to that part of its surface opposing the ice surface. The amount of this heat taken up by the ice varies directly as the temperature differential between the surface of the ice and the conductor surface opposed to it; this differential in turn being largely determined by the distance between the ice and conductor and the substance filling this space. These last two factors are easily varied during the operation of a given refrigerating apparatus, and, therefore, provide a most efficient means for regulating the refrigerating temperatures. The first factor, or temperature differential, changes as a result of the variation of the other two factors and so need only be regarded as a corollary indication of what has taken place.

Thus it is the nature and amount of the substance between the ice and the conductor that governs in this method of temperature control. The rate of heat transfer varies with the substance. Also the rate will vary with the thickness or distance between the ice and the conductor—the further apart the less heat transmitted, and vice versa. The substance can be of any convenient character, preferably a solid, or a fluid like air or CO_2 gas, or a non-freezing liquid, or a combination of substances, depending on the means used for varying the amount of the substances. The substance may be:

(1) A solid in unit form such as sheets of paper, compressed board like cardboard or ⅛" thick pieces of pressed wood, or sheets of metal. These may be put into place to the required thickness when putting the ice into the bunker and changed by lifting out and replacing the ice, or—

(2) A sufficiently rigid piece of material may be used to support the ice and this material in turn raised and lowered in relation to the conductor by any convenient mechanical elevating means operated by hand, or by automatic power applied by the action of a thermostat located in the refrigerated space. In this form the maximum heat flow can occur when the movable support means is in its lowest position, and a diminishing heat flow results as the ice is raised. In operation this form can function by alternately lowering the ice hard down to take up the heat at a higher rate than required and then raising the ice far enough away to take less heat than required, the action being controlled by a thermostat and resulting in the average heat flow required. Here the substance forming the resistance to the heat flow is a solid or a fluid (CO_2 gas and air) or a varying combination of the two. Or as is more usual, this form can function by having the supporting means, under thermostatic control from the refrigerated space, take a stable position, holding the ice in approximately uniform heat-exchange relation with the conductor changing slightly from time to time to meet changing conditions in the refrigerated space, etc. Or this stable position may be achieved without thermostatic control by hand-operated mechanical elevating means. The spaced support for the ice can also take the form of a hollow chamber between the ice and the conductor which is filled, or partially filled, with a non-freezing liquid, such as alcohol, the level of the liquid being regulated by a thermostatically controlled feed. When it is full of liquid, maximum heat transfer results. When the liquid is lowered, the gas filled space above the liquid gives added resistance to the heat flow, or—

(3) Relatively small ice supporting areas can be set up on the conductor where it is opposed to the ice surface, well insulated against heat flow from the conductor, and sufficient heat applied to these areas under thermostatic control from the refrigerated space, to permit the ice to melt more rapidly at these points and the whole ice mass to be lowered nearer the conductor, thus increasing the rate of heat flow as necessary to keep the conductor chilled to the required temperature. Any conveniently controlled source of heat may be used for this purpose including electrically heated resistance wires fixed to the supporting insulated areas; or a fluid, such as air or alcohol circulating in a closed pipe system which picks up heat from the refrigerated space, or outside it, and discharges this heat to the ice through that part of the system on which the ice is supported, namely the insulated small areas, having a thermostatic valve located in the system; or heat may be taken up from the solid metallic conductor or from the air of the refrigerated space by a miniature solid metallic conductor system and transferred as required to the support areas in any of the ways used in the principal heat transfer for refrigerating purposes; or heat may be supplied as required to the insulating supporting areas from the controlled inter-action of suitable chemicals. This way of regulating the heat-resisting space between the ice and the conductor uses principally a gas and air-filled space and a balanced condition such as is described above, although it may also operate by the alternate hard on and off action also described above. This method is based on a fact I have discovered that solid CO_2 when supported on small insulated areas over a metallic conductor which is a source of heat will not melt down over the supporting areas and approach the conductor so long as the supports are colder than the conductor surface opposed to the ice.

(C) Ways of controlling the heat transfer through the conductor itself. These include various means for breaking the continuity of the heat-conduction along the metallic conductor by actually breaking the conductor at some convenient point beyond its point of contact with the refrigerant in order to form a controlled resistance to the heat flow similar to the resistance between the ice and the conductor described above in paragraph B. The break must be so located and sufficiently great as to cut down the heat flow below the minimum required for refrigeration purposes and the controlling means for closing this break must be adequate to increase the heat flow to the maximum requirements. For instance, a break of one-half inch or one inch may be provided and the break mechanically adjusted or closed by hand or thermostatically controlled means, or a suitable separate heat-conducting means automatically moved into place as required. One way of regulating the heat flow across the break, or resistance interposed in the conductor itself, is to provide a short length of flexible metallic heat conductor which is moved in and out of contact

with the conductor, preferably being fastened permanently to one side of the break and moved by thermostatically controlled means in and out of contact with the other side, or maintained in a balanced heat-exchange position with the conductor on the other side of the break. Such a flexible metallic conductor section can be formed from a flexible flat copper cable made up of small woven copper wires and which is thick enough to possess in effect the heat transfer capacity of the conductor itself and still have considerable flexibility of movement. This form is desirable as there is of necessity considerable resistance to heat flow across any break in the conductor and the mending of the break should be over as large an area as possible to cut down this resistance sufficiently. In using copper and aluminum for the conductor in solid sheet or casting form, and also using the same form for connecting the break, it is very hard to make this contact accurately and consistently over a sufficient area because of the tendency of the metals to warp, but if the flexible section as described is interposed, a larger area of close contact can be maintained more consistently because the flexible part can be pressed up hard against the rigid part of the conductor to overcome the surface irregularities and other causes of resistance to heat flow. This is an invaluable feature because the first small break in the contact of the two metallic faces sets up a large resistance to the heat flow, just as the first break between the solid refrigerant and the metal conductor also does.

These three broad ways, which I have described under A, B and C above, of controlling the refrigerating temperature when using solid CO_2 as a refrigerant in combination with the solid metallic conductor are all involved in the general principle of setting up a "conductor resistance" in the path of heat flow formed by the conductor—a principle which is disclosed in my application Serial No. 467,999, filed July 14, 1930, now matured into Patent No. 2,055,158, issued Sept. 22, 1936. A more detailed description is included in this application and various improved means which I have developed for carrying out the principles are now claimed.

The more complete disclosure in this application both of the principles of the solid metallic conductor and of the "conductor resistance" is made for the purpose of providing a basis for the wider use of the invention. There are illustrated herewith, and claims are made for, a few of the particular forms and improvements which are embodied in actual refrigerating apparatus used at the present time. But I do not wish to limit myself to these specific designs as almost every commercial use of a solid refrigerant for the refrigerated storage or transportation of perishable foodstuffs, or other refrigerating purposes, calls for a different design and a different way of applying the principles of the invention. There are always different refrigerating temperatures to be considered, different rates of heat transfer, different forms of storage spaces and different forms of solid refrigerants and bunker capacities—and the conductor must be constructed accordingly.

The attached drawings illustrate various preferred forms of the solid metallic conductor used with various solid refrigerants, also various preferred means for controlling the rate of heat transfer from the refrigerated space to the refrigerant via the conductor, all of which embody advances made since the filing of my application Serial No. 467,999, filed July 14, 1930.

Figures 1 to 10 inclusive illustrate various kinds of storage boxes used for the preservation of perishable foods, for instance ice cream and other frozen foods, and are particularly adapted for the use of dry ice or brine ice. In Fig. 1 is shown a vertical section of an ice cream cabinet using dry ice, in which **1** is the conventional insulated casing; **2** the storage compartment; **3** the metallic conductor formed preferably of single sheet of copper or aluminum; **4** a mass of dry ice supported by that part of the conductor forming the bottom of the ice compartment; **5** is any preferred form of conductor resistance interposed between the ice and the conductor to regulate the temperature of the extended heat absorbing surfaces of the conductor, and hence the temperature of the refrigerated space. For this type of cabinet the conductor is usually of ¼" thick aluminum or ⅛" thick copper. It is more easily made if bent from a single continuous sheet, although the various extended areas can be welded together. In doing so, however, it is most important that the thickness or cross-section is never decreased as the point of heat transfer with the ice is approached, as this would form a bottle neck through which the passage of heat would be restricted. Also it is preferable not to make any joints in the conductor except by welding. If two parts of a copper conductor were soldered together there would be a large drop in temperature across the joint because solder is a much poorer heat conductor than copper. In this form of metallic conductor installation it is preferable to have as large a proportion as possible of the total heat reaching the ice pass through the conductor all the way to the bottom of the ice compartment and there be transferred to the bottom surface of the ice by direct contact, or through the controlled conductor resistance **5**. This can be accomplished by heavily insulating the sides of the ice compartment so that comparatively little heat can get across from the vertical portions of the extended conductor, which are adjacent to the ice compartment, into the interior of the ice compartment there to be transferred to the ice by variable and uncontrollable convection currents or by radiation. If approximately 75% or more of the total amount of heat absorbed by the conductor from the storage compartment is transferred to the bottom of the ice compartment of the conductor then the ice is melted principally on its bottom face, more even refrigerating temperatures can be maintained, and a better control of the rate of heat transfer can be obtained because it is being handled in an established confined path—namely, via the conductor. The situation is analogous to handling water through a hose by which it can be directed and the amount controlled by a valve, as compared with water in the form of rain which is blown about and entirely uncontrollable. Another advantage of the form of conductor shown in Fig. 1 is that because it is disposed around the inside walls of the storage compartment it absorbs a great deal of the heat coming in through the walls before it ever has an opportunity to reach the refrigerated goods; also being disposed mainly in the upper part of the refrigerated space the conductor tends to cut down to a minimum the temperature differential between the top and bottom of the refrigerated space.

Fig. 2 is a horizontal section of Fig. 1 taken at

B—B, Fig. 1 being a section of Fig. 2 taken at A—A. Fig. 3 shows the ice compartment of Fig. 1 arranged for the use of brine ice. This ice 4 which melts at —6° F. (when made of a eutectic mixture of sodium chloride) must be kept in direct contact with the conductor 3 to produce low enough temperatures to preserve ice cream. In this arrangement it is kept in contact with the vertical portions of the conductor which form the sides of the ice compartment. The bottom of the ice compartment is formed of the inclined metal floor 6, and it is not necessary to fold the conductor under the ice compartment. This inclined floor forces the ice by gravity continually up against the conductor side walls as shown. A drain 7 is provided to carry off the melted brine. Fig. 4 is a perspective view of the conductor used in Fig. 1. It illustrates clearly the large heat absorbing surfaces of the conductor as compared with the portion presented at the bottom of the ice compartment for transferring the heat to the ice.

Fig. 5 shows the cabinet of Fig. 1 arranged for transferring a smaller proportion of heat to the dry ice via the conductor; and at the same time permitting a heat transfer to the surface of the ice by convection air currents from the refrigerated space. The extended surfaces of the conductor are cut down to the vertical portions only outside the ice compartment. An opening 8 at the top permits air access to the surface of the ice direct, and on opening 9 at the bottom permits cold air and gas to escape from the ice compartment to the refrigerated space. A valve 11 is arranged to close the lower opening 9 when the refrigerating temperatures drop too low, opening when they rise above the desired point. This valve is operated automatically by the bi-metallic thermostatic spring 10 which is responsive to the temperature of the refrigerated space and is adjusted by means of the lever 12. In this apparatus a principal amount of heat reaches the ice via the conductor 3 and conductor resistance 5 only when the valve 11 is closed. As there are less heat absorbing surfaces and, when the valve is open, there are strong convection currents in the refrigerated space the temperature differentials tend to be higher.

Fig. 6 shows the cabinet of Fig. 1 arranged to retain under pressure in the ice compartment the carbon dioxide gas resulting from the sublimation of the dry ice. This gas can then be piped outside the cabinet and used for carbonating beverages. As it would frequently happen that the amount of heat transmitted to the ice by the conductor from the refrigerated space would not produce sufficient CO_2 gas there is provided an auxiliary means of heating the ice compartment to speed up the sublimation of the ice as required. Imbedded in the sides of the ice box insulation are metal plates 13 to which are secured resistance wires which when supplied by current from battery 14, or other source of electricity, heat up. The plates 13 are then warmed up, heat is transmitted from plates 13 to the ice and an increased production of CO_2 gas takes place without affecting the normal transfer of heat from the refrigerated space via the conductor. The gas escapes through pipe 16 into an auxiliary tank 17 which in turn delivers it for use to outlet 18. Tank 17 is fitted with a pressure safety valve 19, and with a pressure controlled switch 15 which turns the electric current on and off.

Fig. 7 shows a cabinet similar to Fig. 1 with the ice compartment, adapted for dry ice, located in one side. Fig. 8 is a horizontal section of Fig. 7 taken at B—B; Fig. 7 being a vertical section of Fig. 8 taken at A—A. Figs. 9 and 10 show the cabinet of Fig. 7 adapted for use with brine ice as described above in the discussion of Fig. 3. A somewhat larger heat absorbing conductor surface is used than in Fig. 7 because of the higher temperature refrigerant.

Fig. 11 illustrates a vertical section of a household refrigerator using dry ice. The conductor 3 is bent around four sides of a hollow cube within which are located the conventional ice cube freezing trays 33. A dish 34 is placed on one of the shelves directly under the conductor to catch meltage when defrosting. If desired the outside surfaces of the two vertical conductor walls may be finned to provide more heat absorbing surface. Temperatures are regulated by the usual conductor resistance 5.

Figures 12 to 21 inclusive are diagrammatic vertical sectional views of various forms of conductor resistance used for regulating the rate of heat transfer from the refrigerated space to dry ice via an extended metallic conductor. In Fig. 12 the spaced relation, or thickness of conductor resistance, between the conductor 3 and ice 4 is regulated by means of the lever 37 which is pivoted at point 38. The ice is supported on metal plate 35, preferably of the same material as the conductor 3, and this plate raised or lowered by means of the lever 37 which may be operated in any convenient manner. The conductor resistance is formed by the plate 35 in combination with the gas filled space 36.

In Fig. 13 a support for the ice is formed by the hollow tube 39 which is insulated at 40 from the conductor 3. Tube 39 is filled with a non-freezing fluid, such as alcohol, and forms a closed circulating system. Incorporated in the down leg of this system is valve 41 operated by a conventional thermostatic bellows 42, which in turn is responsive to the temperature of the refrigerated space through bulb 43. In operation when the refrigerating temperatures are higher than desired the valve 41 remains open, the liquid circulates in the direction of the arrows, the portion of the tube supporting the ice becomes warmer melting that portion of the ice resting on the tube and allowing the remaining portions of the bottom surface of the ice to approach the conductor 3. This action results in an increased chilling of the conductor, a lowering consequently of the refrigerating temperatures and ultimately a closing of valve 41 when these temperatures go below the thermostat setting. The ice resting on the tube then ceases to melt so rapidly because the tube is insulated from the warmer conductor and the ice begins to melt back from the conductor proper. The spaced relation, or conductor resistance, between the ice and conductor is thus increased, the refrigerating temperatures gradually go up and the cycle is repeated. Any convenient means under thermostatic control may be used to heat the insulated ice support, the one described being only one of several preferred forms.

Figures 14 to 17 inclusive show various ways of introducing the controlled conductor resistance in the path of the metallic conductor itself, as distinguished from its location between the ice and the conductor. In Fig. 14 the continuity of the metal conductor is broken by the gap 3''. This gap is closed by the plate 3' hinged on one side to the conductor at 44. The plate is caused to swing in and out of contact with the conductor surfaces on either side of the gap by means

of the conventional thermostatic bellows **42**, which in turn is responsive to the temperature of the refrigerated space through bulb **43**. In operation when the temperature goes up the bellows expands, pushing the plate **3'** into contact with both sides of the conductor, and an increased flow of heat takes place from the extended portions of the conductor via the conductor to the ice. When the temperature gets too low, the bellows contracts and pulls the plate out of contact. The heat flow is reduced, the temperatures go up and the cycle is repeated. The apparatus illustrated in Figures 15 to 17 goes through exactly the same operation. In Fig. 15 the gap is closed by a loosely packed springy material **3'** such as copper ribbons or shavings. When compressed by the bellows **42** an increased heat transfer takes place because of the greater density and hence conductivity of the material. When the pressure is released the particles spring apart and the heat transfer lessens. A large coiled spring **46** can be imbedded in the particles to assist in separating them. In Fig. 16 a variation of the make and break plate of Fig. 14 is shown. A pair of plates **3'** hinged at **44** are forced in and out of contact with the conductor **3** by action of the bellows **42** working through the member **45** which slides in contact with plates **3'**. A spring **46** helps maintain this contact. In Fig. 17 the break is closed by a section of flexible conductor preferably made of woven copper wire. It is secured firmly to the fixed conductor on one side of the break, and is moved into contact on the other side of the bellows. In Fig. 18 the same flexible conductor section is used in slightly different form and location. The bellows action is applied by lever **47** which is pivoted at **48**.

Figures 19 and 20 show the use of a liquid confined in the conductive path, the level of which controls the heat transfer rate. The liquid level in turn is controlled by the usual thermostatically operated bellows. In Fig. 19 a conductor resistance **5** is provided between the ice and the conductor in the form of a hollow metal pad filled with alcohol. The pad is connected with a bellows **51** the two forming a closed fluid system containing a fixed amount of alcohol just enough to completely fill the pad when the bellows is contracted. A second bellows **42** operates under thermostatic control from the refrigerated space as previously described to contract and expand bellows **51** containing the alcohol. When the temperature of the refrigerated space goes up, bellows **42** expands, bellows **51** contracts and pad **5** is filled with liquid permitting a maximum heat transfer. As the temperature drops, bellows **42** contracts, bellows **51** expands and the liquid **49** in the pad drops leaving an air filled space in the pad over the liquid which is a much poorer conductor of heat to the ice than the liquid. When the temperature again rises the air space is pressed out and the cycle is repeated. A very small hole in the top of the pad permits the air to get in and out. Fig. 20 shows an apparatus operating in the same way as Fig. 19, except that the fluid compartment is located in a definite break in the conductor as shown outside the ice compartment.

Fig. 21 shows a definite break in the conductor path where the heat transfer across the break is principally by radiation between two relatively large opposing surfaces of the conductor. In this apparatus the heat transfer across the break is regulated by means of a series of thin polished bright metal plates **52** arranged on pivots **53** to swing like the leaves of a shutter from a horizontal to a vertical position. When they are in a horizontal position the maximum heat transfer will take place between the opposing faces of the conductor and the refrigerating temperatures will be lowest. When in a vertical position, the amount of radiated heat transfer will be cut down by reflection from the bright surfaces and the temperatures will be higher in the refrigerated space. The action of the shutters can be controlled by any convenient known mechanical means, operated by hand or thermostatically under control from the refrigerated space.

I claim:

1. A refrigerating apparatus having a compartment for a solid refrigerant and a space to be cooled, a solid metallic heat conductor with which solid refrigerant in the refrigerant compartment is to be maintained in heat-conductive relation, said conductor having extended surfaces for heat absorption from the space to be cooled, the capacity of said conductor to transmit heat along in the direction of the refrigerant from the surfaces for heat absorption being sufficient, by reason of its thickness with respect to the heat conductivity of the metal from which it is formed and the area of said extended surfaces exposed for heat absorption to maintain said heat-absorbing surfaces at an effective refrigerating temperature lower than that of the space to be cooled, means for controlling and regulating the transfer of heat from the refrigerated space or material to the refrigerant, said means being formed by a break in the metallic continuity of the conductor, and means for varying the heat flow across said break.

2. A refrigerating apparatus having a compartment for a solid refrigerant and a space to be cooled, a solid metallic heat-conductor with which solid refrigerant in the refrigerant compartment is to be maintained in heat-conductive relation, said conductor having extended surfaces for heat absorption extending from an upper portion of the space to be cooled to a lower portion thereof, whereby heat may be absorbed by said surfaces from the upper portion of said space and transmitted downwardly to the solid refrigerant, the capacity of said conductor to transmit heat along in the direction of the refrigerant from the surfaces for heat absorption being sufficient, by reason of its thickness with respect to the heat-conductivity of the metal from which it is formed and the area of said extended surfaces exposed for heat absorption to maintain said heat-absorbing surfaces at an effective refrigerating temperature lower than that of the space to be cooled, means for controlling and regulating the transfer of heat from the refrigerated space or material to the refrigerant, said means being formed by a break in the metallic continuity of the conductor, and means for varying the heat flow across said break.

EDWARD RICE, JR.