

Oct. 27, 1953

W. E. COWIE ET AL

2,656,586

PILE FABRIC

Filed May 25, 1950

3 Sheets--Sheet 1

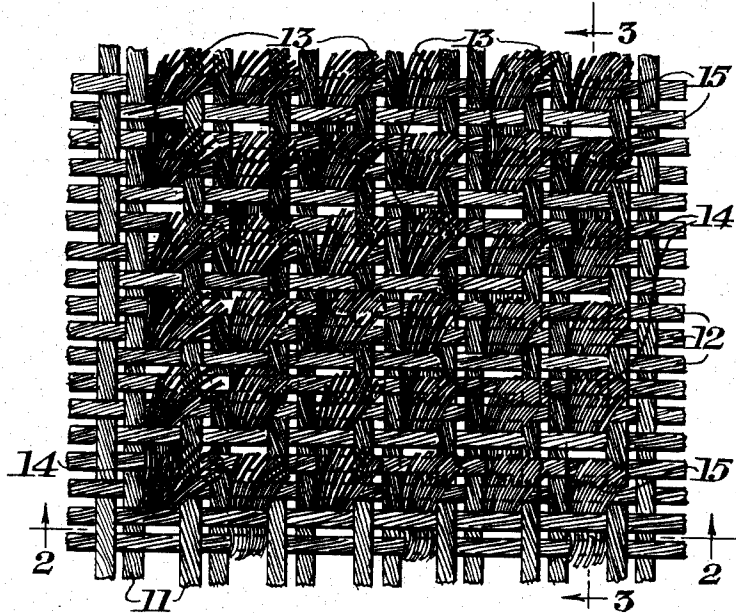


FIG. 1

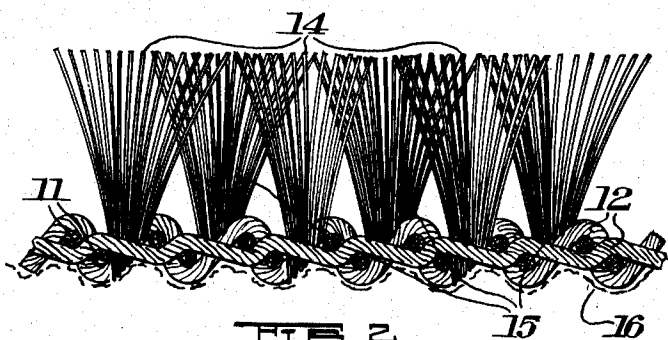


FIG. 2

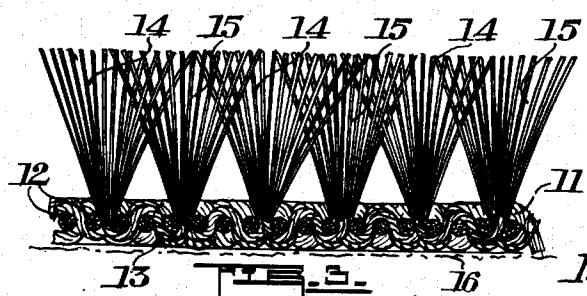


FIG. 3

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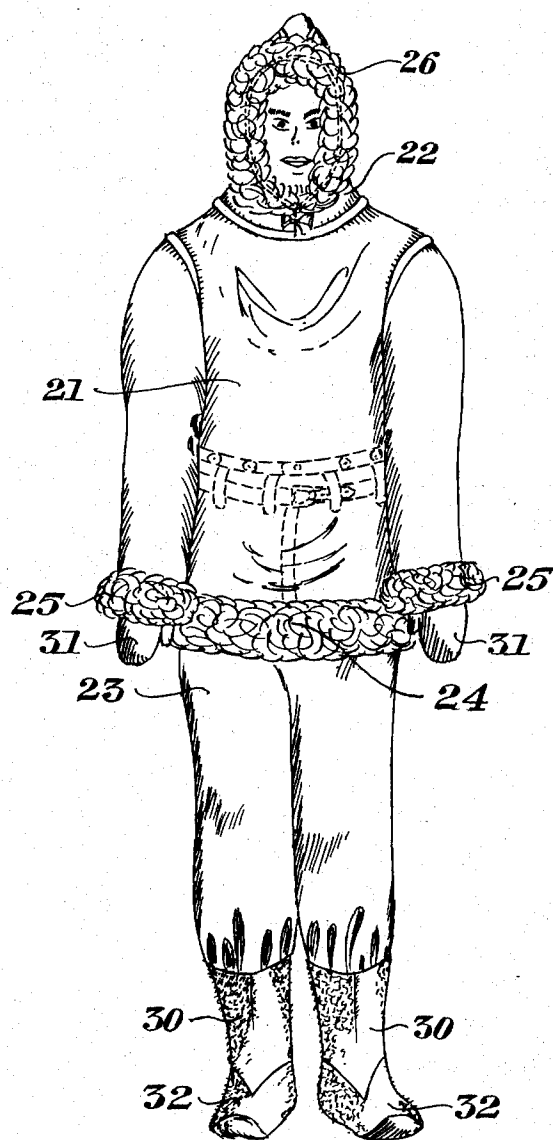


FIG. 4

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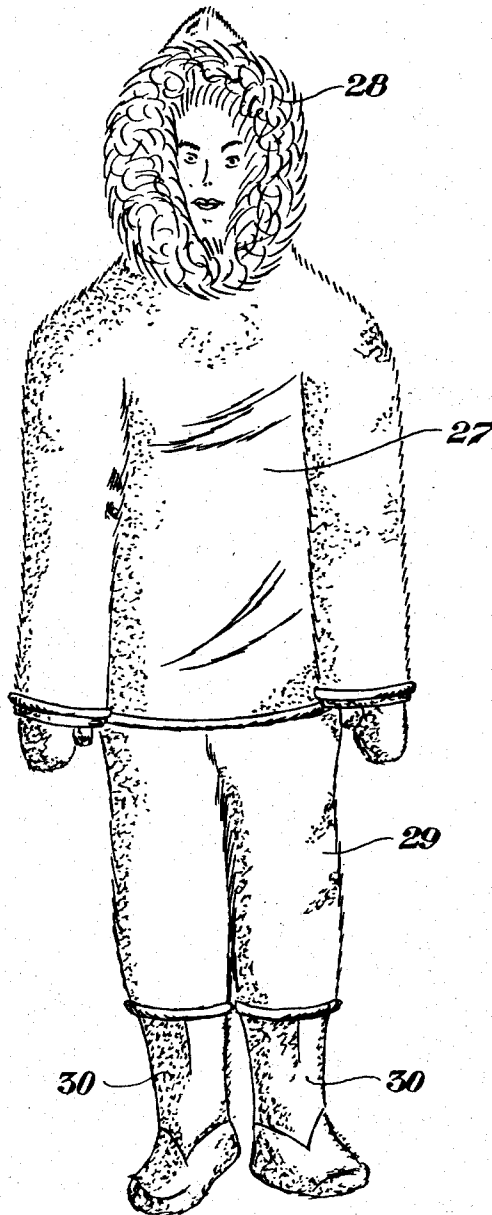


FIG. 5

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UNITED STATES PATENT OFFICE

2,656,586

PILE FABRIC

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Application May 25, 1950, Serial No. 164,086
In Canada May 28, 1949

12 Claims. (Cl. 28—80)

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This invention is for improvements in or relating to pile fabrics for cold weather clothing, particularly for wear under the climatic conditions of the polar regions.

An object of the invention is to provide an improved light weight pile fabric which is capable of readily shedding frost substantially without detriment to the fabric and which has thermal insulation, vapour permeability and other characteristics appropriate to its employment as a fur substitute in body clothing for wear under the severe climatic conditions of the polar regions.

A further object of the invention is to provide such a fabric which can readily be mass-produced by conventional weaving processes.

For long term wear under polar climatic conditions, body clothing must either prevent the accumulation of frost within the insulating layers or the clothing fabric must be so designed that such accumulations may periodically be removed.

The accumulation of frost within the insulating layers may of course be prevented by enclosing them within a water impermeable envelope but this has not so far proved to be practical. In regard to the periodic removal of frost it has long been known to employ a fur ruff around the the edge of a parka to protect the face of the wearer under polar climatic conditions and periodically to remove from the ruff frost formed by condensation of moisture exhaled in the breath and a consistent preference has been shown for wolverine fur as an edge trimming. This preference has been ascribed to various factors but appears in general, to be based upon the superior frost-shedding or de-icing properties of wolverine fur. Thus, while wolverine fur collects frost or ice in the same way as any other fur, when the frost has changed to ice it may be removed by knocking and brushing without detriment to the

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evaluated the several other factors bearing upon the construction of a pile fabric which is to be capable of affording adequate protection to the wearer under polar climatic conditions.

As a result of our investigations a variety of pile fabrics have been constructed which have been fashioned into body clothing and tested under severe operational conditions in the Arctic. The novel pile fabrics and body clothing so produced are considered to constitute a notable improvement over fabrics and fabric clothing hitherto available for cold weather protection and even to surpass in performance the caribou fur clothing of admitted excellence evolved by the Eskimos through centuries of experience with the Arctic climates.

The several characteristics of our improved fabrics, which characteristics are to a certain extent inter-related, will be discussed under separate headings as follows:

FROST REMOVAL

We are satisfied that the superiority of wolverine hair can adequately be accounted for solely on the basis of its mechanical properties. Furs not yet studied may possess similar mechanical properties but, of those tested, wolverine guard hair fibre is unique in exhibiting all the following qualities:

- (a) A high tensile strength,
- (b) A firm anchorage to the pelt,
- (c) A smooth surface, and
- (d) The greatest filament diameter within the Carnivora order, with consequential exposure of less surface to ice per given weight of hair.

The average measured characteristics of the guard hairs of certain of the different furs investigated are shown in Table I as follows:

TABLE I

Constant	Wolverine	Muskkrat	White Tail Deer	Caribou	High	Low
Length in inches.....	2.93	1.33	1.58	2.64	Wolverine.....	Muskkrat.....
Diameter in inches.....	0.00378	0.00232	0.0106	0.0094	W. T. Deer.....	Do.....
Weight per inch in gms.....	0.00017	0.000063	0.00013	0.00012	Wolverine.....	Do.....
Density (gms./cc.).....	0.93	0.91	0.088	0.080	do.....	Do.....
No. of guard hairs per in.....	1888		2740	6660		
Tension in lbs. on Scott Tester.....	0.18/1 7/8"		0.05/0.55"	0.04/0.55"	Wolverine.....	Caribou.....

fur, whereas most other furs are permanently harmed by this treatment.

We have investigated the chemical and physical characteristics of wolverine hair and of the hair of a number of other fur-bearing animals, to ascertain why wolverine fur is superior to others in shedding frost and we have surveyed and

A standard Scott tester (used for measuring the tensile strength of fabrics) was employed for determining the tensile strength of the various hair fibres and our results show that it take a pull of 0.18 lb. (81.7 gms.) to break a single 1 7/8" long wolverine hair weighing 0.00017 gm./inch, which corresponds approximately to a filament of 60.25

denier. The tensile strength of wolverine hair is therefore shown to be approximately 1.36 gms. per denier. Only very short samples were available for the tests, the lengths of the samples being dependent upon the length of guard hair as it was taken from the pelt, which in the case of wolverine was $1\frac{7}{8}$ " in most cases. To correctly evaluate the utility of a particular hair in shedding frost, the strength of the anchorage must of course be considered as well as the tensile strength of the hair fibre but our results clearly indicate wolverine guard hair to be much higher in tensile strength than any other fur tested.

THE PILE FILAMENTS

Our experiments have pointed to the desirability of a pile fabric having monofilaments firmly anchored to the ground cloth, to withstand the stress of combing and brushing to remove matted frost, and to the employment of pile filaments selected with regard to the following special characteristics:

- (i) They should be straight, should have a smooth surface and should be substantially uniformly distributed over the fabric surface,
- (ii) They should have a tensile strength of not materially less than that of wolverine fur guard hair.
- (iii) They should retain their flexibility and strength at polar sub-zero temperatures and preferably down to temperatures at least as low as -60° F.
- (iv) They should have a low-moisture-absorption capacity at high relative humidities (i. e. less than that of cotton fibre),
- (v) They should have a stiffness sufficient to maintain themselves in a substantially separate condition to resist compression and felting of the pile so to allow it to be combed or beaten to remove accumulated frost.

The pile filaments to be employed in accordance with the invention preferably consist of extruded non-cellulosic thermoplastic filaments preferably selected from the group comprising the polymeric amides (known generically as nylon), or the vinyl resins comprising, for example, the copolymers of vinyl chloride and vinyl acetate (known for example, under the registered trademark "Vinyon") or the vinylidene chloride polymers (known, for example, as saran). Alternatively, polyacrylonitrile fibres (known under the trade-mark "Orlon") have characteristics suitable for use in accordance with the invention.

Of the foregoing materials, high tensile nylon filaments have proved eminently satisfactory in practice and fully satisfy the prescribed special characteristics in being straight, in having a smooth substantially cylindrical surface, in having an average moisture regain of 6.30% at relative humidities as high as 90%, (approximately half that of cotton under similar conditions), in possessing a high tenacity (about 5 to 7 grams per denier dry and about 4.4 to 6 grams per denier wet), and in retaining their strength and in showing only slight increase in elongation at temperatures as low as -80° C.

Nylon filaments are further particularly suited for use as a pile thread in clothing fabrics in being inert and clean, in possessing no harmful toxological properties and in being relatively incapable of supporting the growth of mildew, fungi or bacteria.

PILE FILAMENT DENIER

As previously stated, the pile filaments should

have a tensile strength not materially less than that of wolverine fur guard hair and a stiffness sufficient to maintain themselves in a substantially separate condition to resist compression and felting. We have determined that a 10-denier monofilament with characteristics similar to that of nylon is about the lowest denier pile filament which is suitable for use in our improved fabric. The optimum denier is the stiffest monofilament which can be worn in comfort towards the skin; we estimate this to be at 20 to 30 denier when no underclothing is worn to about 50 or possibly 75 denier with underclothing.

THE PILE STRUCTURE

In addition to the foregoing requirements, a pile fabric for body clothing under polar conditions must be light in weight, flexible and have a low bulk and must possess thermal insulation and vapour permeability characteristics appropriate to the climatic conditions concerned. The thermal insulation of the fabric is determined, inter alia, by the thickness and state of immobility of the air layer trapped within the pile and, therefore, varies with the length of the pile. Moreover, if the fabric is subject to conditions of use tending to flatten the pile, the thermal insulation depends also upon the ability of the pile to resist compression and to return to its original condition when the compression load is removed. The ability of a pile fabric to retain its thickness under intermittent compression loading is thus a function of the stiffness and resilience of the pile filaments and also of the overall bulk density of the pile, which varies as the number of the pile threads. The nature of the ground cloth employed, the denier of the pile thread, the resistance of the pile thread to weaving stresses and the technical limitations of pile weaving machinery, are all factors which operate to set a practical upper limit to the count of the pile filaments. The overall bulk density of the pile is also largely influenced by the overall weight of the fabric. In the course of our experiments it has been determined by trial in the Arctic that clothing which weighs more than 12 to 14 lbs., including handgear and footgear, tires the wearer rapidly in proportion to the increase in weight. The maximum practicable weight of body clothing for the conditions envisaged is of the order of 10 to 12 lbs. It is, therefore, of critical importance that the bulk density of the fabric be held to a minimum, which calls for the employment of a ground cloth which is as light as possible and for a pile having a minimal bulk density consistent with the required insulation.

In setting the physical limits of the pile structures which will yield fabrics sufficiently warm for body clothing under polar conditions, we have studied the structure of various furs and we have selected caribou as a standard of excellence, proved by centuries of use by the Eskimo to be the most suitable for body clothing in the Arctic winter, to be attained or surpassed. The features which render caribou skin so desirable are its low bulk, stiffness and weight combined with adequate warmth and its ability to withstand the conditions of service over periods of months while on the trail. Thus, Stefansson states in his "Arctic Manual" (1945) that "As protection against the weather of the various seasons, the Eskimos have developed on the whole better garments than probably any people in history" and further, "caribou is the best of all native Arctic materials for winter clothes . . .". For use in pile fabrics required for insulating purposes large

diameter, low density, tightly packed filaments are desirable such as occur naturally in caribou fur which has 6660 guard hairs per square inch with a diameter of 0.024 cm. and a density of 0.080. Wolverine guard hair on the other hand, has a diameter of 0.0096 cm. and, therefore, to maintain the same proportion of diameter to number of hairs as caribou, should have 16,700 guard hairs per square inch. However, the controlling factor is the overall bulk density, as that is a measure of the weight of the material for a given amount of insulation, and the specific gravity of caribou guard hair is only a fraction of that of wolverine and of artificial filaments possessing the required tensile strength so that it is necessary to use a proportionately lower denier of synthetic filament to obtain the optimum bulk density of the pile fabric. With these considerations in mind we have experimented with a number of pile fabrics utilizing artificial pile warp threads of different denier selected with regard to the special characteristics for frost-removal discussed above and packed to different degrees and we have found that pile fabrics possessing appropriate thermal insulation, light weight, flexibility and low bulk density can be obtained by employing a number of pile filament ends per unit area of fabric which is of the same order as that of the guard hair in caribou fur. Good thermal insulation can, however, be obtained notwithstanding that the number of pile filaments per unit area of fabric varies between wide limits, provided that a corresponding adjustment is made in the denier of the filaments. The practical limits of filament count have been found to coincide approximately with the range 2500 to 18,500 filament ends per square inch of pile area.

To assist in arriving at appropriate packing densities using filaments of different denier we have formulated an approximate rule relating the number of filament ends per square inch of pile area and the denier of filaments concerned; the rule provides that the number, N , of filament ends per square inch of pile area should be of the order of the quotient of the expression k/d , where k has a value between 200,000 and 300,000 and d is the denier of the filaments, the filaments being considered as solid and as having a specific gravity approximating to that of dry nylon fibres (i. e. of the order of 1.14). In the present specification the expression "number of filament ends per square inch" connotes the total number of individual pile filaments which stand out from the ground cloth. Thus, supposing a pile warp thread is used consisting of 220 denier 16 filament thread used singly, each tuft then consists of a bundle of 16 filaments anchored in the ground cloth intermediate their ends. There will thus be a total of 32 filament ends standing out from the ground cloth for each tuft. Assuming the number of separate tufts per square inch to be 482, the total number of filament ends per square inch is given by $32 \times 482 = 15,422$.

PILE LENGTH

The weight per unit area of the fabric is, of course, approximately proportional to the pile length (other factors remaining constant) and it is essential in using the fabric for body clothing for the climatic conditions in question, to keep the pile length at a minimum consistent with securing the required thermal insulation. We have established that a relatively short pile is adequate to immobilize the air within the pile to provide the required thermal insulation.

While there is no sharply defined lower limit for pile length, our experiments indicate that the minimum pile length for inner garments for Arctic wear is of the order of $\frac{1}{4}$ inch. The thermal insulation of the clothing is almost directly proportional to the pile thickness and we have determined by test that an Eskimo type construction must consist of two $\frac{1}{4}$ inch pile layers to be effective in the Arctic winter climate. For inner layers in moderately cold climates the practical lower limit of pile length is considered to be $\frac{1}{8}$ inch. The foregoing pile thicknesses are also such as to allow the clothing to follow the contours of the body more closely by compressing the pile to some degree on the inside garment over protruding irregularities of the body. It is of advantage to use thicker piles (for example up to about $\frac{3}{4}$ inch) for extreme cold, in which case the pile filaments should be selected at a larger diameter and of the filament range to maintain adequate compression resistance and to keep the pile in an erect unmatted condition. Under the latter conditions it is also advantageous to use hollow or cellular pile filaments to assist in keeping the weight of the clothing below the limit of tolerance, i. e. 15 lbs.

AIR AND VAPOUR PERMEABILITY

The air and water vapour permeability of the ground cloth of the fabric is of critical importance for body clothing under polar climatic conditions. The lower limit of air permeability of the fabric is, of course, zero and is preferable if it can be attained without unduly decreasing the water vapour permeability. When the fabric is to be used for clothing in areas subject to high velocity winds of the order of more than 25 miles per hour at sub-zero temperatures, it is of prime importance that the air permeability be not greater on the average than about 5 cubic feet per square foot of fabric per minute, as measured at a pressure differential of $\frac{1}{2}$ inch of water in the Schiefer and Boyland apparatus described in Research Paper R. P. 1471 of the Journal of Research of the United States Department of Commerce, National Bureau of Standards, vol. 28, May 1942. At lower velocity winds the air permeability may be somewhat higher but should be maintained at a value not in excess of 10 cubic feet/square foot/minute, measured as above, for use in wind velocities from 25 miles per hour down to 10 miles per hour. The air permeability of caribou clothing skin measured by the above method ranges from about 0.5 to about 6.0 cu. ft./sq. ft./minute.

The water vapour permeability should on the other hand be as high as possible consistent with a low air permeability and should preferably be not less than a dry tanned deer or caribou skin as set forth hereinafter. There is no sharp demarcation of desirable vapour permeability but vapour impermeable materials produce an undesirable accumulation of moisture within the clothing. As a minimum requirement, the pile fabric should have a water vapour transmission per square metre per single layer per hour of 20 grams for a vapour pressure difference of 10 mm. of mercury, of 50 gms. for a vapour pressure difference of 40 mm. of mercury and of 80 gms. for a vapour pressure difference of 50 mm. of mercury, measured at body temperature on one side and 0° C. on the other side.

The desired limits of air and vapour permeability may be achieved while simultaneously securing good anchorage of the filaments to the ground cloth and without adding substantially

to the overall weight of the fabric by a controlled application of a cementing or bonding agent of suitable viscosity to the ground cloth. As bonding agent, we may employ pre-vulcanised or vulcanisable natural, synthetic or reclaimed rubber, coated from aqueous emulsion or from solution onto the back of the woven fabric so as lightly to impregnate the back and to form a thin continuous liquid film over the backing. The rubber bonding agent must have a high viscosity, of the order of 1500 centipoises, so that it does not penetrate the backing and run into the pile. The coated rubber is then dried, or cured and dried, and the amount of rubber applied is so controlled that the drying process ruptures and thin liquid film over the larger pores in the backing thereby providing passages for vapour transmission. The weave of the ground fabric ensures that sufficient pores are available for the required vapour transmission and that the pore size is small enough to keep the air permeability down to the required limits. The rubber also locks the pile filaments firmly to the backing and the light penetration of the rubber into the ground cloth reduces the water absorbency of the ground cloth. An amount of rubber not exceeding 1 ounce (avoirdupois) per square yard of fabric has been found to provide excellent filament anchorage and to give air and vapour permeability within the required limits.

Thermoplastic bonding agents may alternatively be employed in emulsion or in solution. The required low air permeability of the backing may also be achieved without impregnation by a fluid bonding agent either by the closeness of the weave of the ground cloth or by using thermoplastic fibres in the backing yarns and by passing the fabric back-down over heated rolls to flatten out the filaments and to seal up the back of the fabric.

While our experiments have shown that pile fabrics having an air permeability not greater than 5 cubic feet per minute are suitable for body clothing under the most severe conditions of a polar winter, it should be understood that pile fabrics which are substantially impermeable to air are also within the scope of the invention provided that the required vapour permeability limits are conserved. The overall weight of such substantially air-impermeable structures is, however, in general greater than that of the equivalent air-permeable structures which latter constructions are accordingly preferred on the basis of weight.

PILE WEAVE

The pile thread may be woven into the ground cloth by the well-known cut pile weaving technique and the so-called W-weave is preferred as enhancing the anchorage of the pile filaments.

THE GROUND CLOTH

The weave of the ground cloth is susceptible to wide variation but should be selected having regard to the following special characteristics:

- (a) High flexibility with a low weight,
- (b) High tensile strength per thread to withstand weaving stresses,
- (c) High tensile strength per unit cross section to withstand wearing stresses, and
- (d) A low moisture absorbency.

A cotton-warp and a cotton-filled ground cloth has given good results, a nylon-warp and a cotton-filled ground cloth has also proved sat-

isfactory and an all-nylon ground cloth has also been employed and, of the three structures, is preferred owing to the lower inherent moisture absorbency of nylon.

CLOTHING CONSTRUCTION

The flexibility of the pile fabric when made into body clothing should be high to provide ease of movement and to conserve the energy of the wearer for work tasks. The drape of the fabric is also important in ensuring that when made into clothing it does not hang too far from the body and leave voids beneath. Such voids chill the wearer due to convection currents and to excessive ventilation due to flapping of the clothing when the wearer moves. The wearer should also have little consciousness of the bulk of the clothing and in this respect the resistance to compression under the armpits and around the joints is important. To achieve perfection the clothing should simulate the fluidity of air.

We have established that maximum flexibility, the required drape, minimal consciousness of bulk and minimal resistance to compression can be achieved by the Eskimo style of garment comprising two layers of pile fabric in a back-to-back construction. With this arrangement, the resistance to motion across the face of the pile is very slight as small forces at right angles to the pile filaments easily deflect the pile and allow movement of the contacting body relative thereto. The ends of the pile filaments move in the direction of the deflecting force and when flattened present the smooth rounded surface of the sides of the filaments to the contacting object. Such material has very little tendency to snag on surrounding objects and allows the wearer to reach, or enter bodily into areas difficult of access to the wearer of conventional flat woven fabric clothing.

In order that the invention may be more fully understood, several examples of pile fabric constructed in accordance with the invention will now be described, the construction being illustrated in Figures 1, 2 and 3 which:

Figure 1 is a diagrammatic plan view of the face of the pile fabric greatly enlarged to show the fabric and pile structure.

Figure 2 is a cross-sectional elevation of the fabric weftways on the line 2—2 of Figure 1 and

Figure 3 is a cross-sectional elevation of the fabric warpways on the line 3—3 of Figure 1.

A specific embodiment of body clothing intended for wear in the polar regions and consisting of pile fabric pursuant to the invention will also be described with reference to Figures 4 and 5 in which:

Figure 4 shows the inner garments of a parka and trousers assembly, and

Figure 5 shows the assembly completed by the addition of an outer parka and outer trousers.

The pile fabric shown diagrammatically in Figures 1 to 3 consists of a ground cloth made up of warp yarns 11 and weft picks or filling yarns 12, and a pile comprising a plurality of individual tufts 13 of pile warp yarns beaten up in a tight W-weave with the weft yarns. The tufts 13 are distributed uniformly over the ground cloth and in the direction of the warp there is one tuft for every six weft or filling yarns, giving a ratio of 1 to 6 for tufts to picks, and in the direction of the weft, there is one tuft for every two ground warp yarns. If the number of warp ends per inch is designated by x and the number of filling yarns

per inch is designated by y , the total number of tufts per square inch is then given by

$$\frac{x \times y}{6}$$

however, each tuft 13 furnishes two bundles 14 and 15 of filaments which stand substantially straight out from the ground cloth and constitute the pile and the total number of upstanding pile filament ends is thus given by

$$\frac{x \cdot y \cdot z}{6}$$

where z is the number of individual filaments per tuft. In the various specific constructions described hereinafter, the total number of upstanding pile filament ends per square inch is calculated from the expression

$$\frac{x \cdot y \cdot z}{6}$$

by substituting the values for x , y and z given in each example.

The back of the ground cloth also carries a rubber coating 16 or other bonding agent applied as previously described in an amount not exceeding 1 ounce (dried weight) per square yard of fabric. The coating 16 is so thinly distributed that the texture of the warp and filling yarns is clearly visible and apparent to the touch. Nevertheless, the carefully controlled application of a bonding agent in this small amount is adequate to provide air and vapour permeabilities within the required limits and firmly to anchor the pile threads in the ground cloth.

Specific examples of pile fabrics constructed in accordance with the invention are as follows:

Example I

$\frac{3}{8}$ " NYLON PILE, COTTON GROUND CLOTH

Backing:			
Warp	2/30	carded cotton,	48
		ends/inch (x).	
Filling	1/12	carded cotton,	72
		picks/inch (y).	
Weight		0.4 lb./square yd.	
Pile:			
Length	$\frac{3}{8}$ inch.		
Weave	W, warp thread.		
Material	nylon; 75 denier monofilament.		
Filaments/tuft	Six (z).		
Filament ends/in. ²	3460 (approx.).		
Fabric weight	2.8 pounds/square yd.		
Air permeability	2.0 to 5.0 cu. ft. of air/sq. ft./min. (Schiefer & Boyland).		
Bonding agent	Rubber applied to the back of the ground cloth and weighing 1 oz./sq. yd.		

In the construction of Example I, each tuft consists of six filament ends giving twelve filaments per tuft upstanding from the ground cloth. Applying the parameters of Example I in the formula $N=k/d$, we have d equal to 75 and N equal to 3460, giving a k value of 259,500.

Example II

$1\frac{1}{8}$ " NYLON PILE—COTTON GROUND CLOTH

Backing:			
Warp	2/30	carded cotton,	48
		ends/inch.	
Filling	1/12	carded cotton,	60
		picks/inch.	
Weight		0.4 lb./sq. yd.	
Pile:			
Length	$1\frac{1}{8}$ inches.		
Weave	W, warp thread.		
Material	Nylon; 220 denier, 16 filaments, in pairs.		
Filaments/tuft	Thirty-two.		
Filament ends/in. ²	15,360 (approx.).		
Fabric weight	39 ozs./square yd.		
Air permeability	2.0 to 5.0 cu. ft. of air/sq. ft./minute.		
Bonding agent	Rubber, applied to the back of the ground cloth and weighing 1 oz./sq. yd.		

The construction of Example II affords sixty-four filament ends per tuft standing out from the ground cloth. Substituting in the expression $N=k/d$, d is equal to 220/16, and k is then equal to:

$$15,360 \cdot \frac{220}{16} = 211,200$$

Example III

$\frac{3}{8}$ " NYLON PILE—COTTON GROUND CLOTH

Backing:			
Warp	2/30	carded cotton,	62
		ends/inch.	
Filling	1/40	carded cotton,	92
		picks/inch.	
Weight		0.24 lb./sq. yd.	
Pile:			
Length	$\frac{3}{8}$ inch.		
Weave	W, warp thread.		
Material	Nylon; 220 denier, 16 filament used singly.		
Filaments/tuft	Sixteen.		
Filament ends/in. ²	15,400 (approx.).		
Fabric weight	15.4 ozs./sq. yd.		
Air permeability	2.0 to 5.0 cu. ft. of air/sq. ft./minute.		
Bonding agent	Rubber, applied to the back of the ground cloth and weighing 1 oz./sq. yd.		

In the construction of Example III, k is equal to 211,750.

Example IV

$\frac{3}{8}$ " NYLON PILE—NYLON AND COTTON GROUND CLOTH

Backing:			
Warp	140 denier, 68 filament nylon, 64 ends/inch.		
Filling	1/40	carded cotton,	104
		picks/inch.	
Weight		0.24 lb./sq. yd.	
Pile:			
Length	$\frac{3}{8}$ inch.		
Weave	W, warp thread.		
Material	Nylon; 220 denier, 16 filament used singly.		
Filaments/tuft	Sixteen.		
Filament ends/in. ²	17,700 (approx.).		
Fabric weight	17.1 ozs./sq. yd.		
Air permeability	1.0 to 4.0 cu. ft. of air/sq. ft./minute.		
Bonding agent	Rubber, applied to the back of the ground cloth and weighing 1 oz./sq. yd.		

In the construction of Example IV, k is equal to 243,375. The conductivity factor of the material of Example IV has been measured and found to be 0.58 B. t. u./hour/per sq. ft./inch thickness.

Example V

$\frac{3}{8}$ " NYLON PILE, NYLON GROUND CLOTH

Backing:			
Warp	140 denier, 68 filament nylon, 62 ends/inch.		25
		turns/inch.	
Filling	175 denier spun nylon,		103
		picks/inch.	
Weight		4.8 ozs. per square yard.	
Pile:			
Length	$\frac{3}{8}$ inch.		
Weave	W, warp thread.		
Material	Nylon; 215 denier 17 filament used singly.		
Filaments/tuft	Seventeen.		
Filament ends/in. ²	17,700 (approx.).		
Fabric weight	18.3 ozs./square yd.		
Air permeability	0.4 cu. ft. of air/sq. ft./min.		
Bonding agent	Rubber, synthetic, applied to the back of the ground cloth and weighing 1 oz./sq. yd.		

The pile fabric may be treated, for example, after weaving and before or after bonding, depending upon the bonding agent employed, by a chemical surface agent to give the fabric a high degree of water repellency and a low water absorption. The silicones, such as amino silane or the methyl chloro silanes, having a high contact angle with water have been found to serve as suitable surface agents. The amino silanes may be applied from solution or in the form of the liquid per se and the methyl chloro silanes may be applied from emulsion. Thus, the woven

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pile fabric may be immersed in a 1% solution of amino silane in carbon tetrachloride and then passed through wringer rolls under pressures of the order of 200 lbs. per inch width of fabric and afterwards through a curing oven at 350° F. for four minutes. The weight of silicone applied is about ½ oz./sq. yd on a ⅜" pile fabric. The chemical surface agent may alternatively be applied to the yarn before weaving.

The calculated overall bulk densities of pile fabrics constructed in accordance with Examples I to V are as follows:

	Lbs./cu. ft.
Example I (⅜" pile, 75 denier filaments)-----	5.0
Example II (1⅜" pile, 13.7 denier filaments)-----	2.7
Example III (⅜" pile, 13.7 denier filaments)-----	3.4
Example IV (⅜" pile, 13.7 denier filaments)-----	3.8
Example V (⅜" pile, 12.6 denier filaments)-----	4.1

The bulk densities set forth above were calculated from the weight of fabric per square yard given in Examples I to V by multiplying the weight per square foot of fabric by the number of the thicknesses of fabric required to fill a foot cube without compressing. It will be appreciated that the bulk density calculated as above will be inversely proportional to the pile length where the construction of the backing and the density of the pile are constant.

The bulk density of caribou skin varies somewhat according to the pelt and the rigour of the

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over the weft yarns of the backing. The pile filaments are thereby individually exposed to the bonding agent so facilitating their firm anchorage in the ground cloth and the bonding agent is extended so that the required air and vapour permeabilities can be secured with a minimum weight of bonding material.

The vapour permeabilities of representative samples of caribou skin and of our improved pile fabrics have been measured in terms of their water-vapour transmission rates at various temperature differentials and the results are set forth in the tables 2 and 3 below:

TABLE 2

Caribou skins as used in clothing

Temperature and H ₂ O vapour pressure on back		Temperature and H ₂ O vapour pressure on pile side		Water vapour transmission
°C.	mm. Hg	°C.	mm. Hg	gms./hr./m. ²
38	50	29	9.6	63
25	24	25	13.8	22
21	18.6	21	11.2	23
38.5	51	0	4.6	115
37.5	48.5	0	4.6	93
38.5	51	0	4.6	86
38	50	-20	0.8	55

TABLE 3

Nylon pile fabrics

Fabric Type	Temperature and H ₂ O vapour pressure on back		Temperature and H ₂ O vapour pressure on pile side		Water vapour transmission
	° C.	mm. Hg	° C.	mm. Hg	gms./hr./m. ²
Example II—1⅜" pile; rubberized-----	28.5	29	28.5	9.9	30
	38	50	38	9.9	62
	38	50	-6	3.0	259
Example IV—⅜" pile not rubberized. Air permeability 60.80 cu. ft./min.-----	38	50	0	4.6	220
	27	27	13.5	26	
Example IV—⅜" pile; rubberized-----	38	50	0	4.6	194
	38	50	-19	1.0	202
Example V—⅜" pile; rubberized-----	38	50	-16	1.15	293

dressings treatment but has a value from about 3.75 to about 5.3 lbs./cu. ft. The pile fabric in accordance with the invention thus has a bulk density which is closely comparable with the best values obtained for caribou, and which is substantially constant over an extreme range of filament denier.

The pile warp yarns employed in Examples I to V hereof are composed of a plurality of filaments twisted together in some degree to assist the weaving process. The nylon yarn employed is, however, such that no permanent twist remains in the pile yarn after the pile warp threads have been cut following weaving by the known cut pile processes and, as a result, the filaments separate from each other to product a very regular pile structure with the individual filaments spaced uniformly throughout the pile for a substantial portion of their free length. In order to achieve the necessary pile count in accordance with the invention, the pile warp yarns have to be beaten up very tightly in the weft yarns. As a result of this beating up, the individual filaments of the weft yarns become displaced from their twisted cylindrical condition in the region of the bottoms of the W tufts, and become spread out into a ribbon formation where they bend

It will be noted that the vapor permeabilities for the nylon pile fabrics given above all compare favourably with those of caribou. The all nylon structure of Example V is particularly good in having a high water-vapour transmission rate and an extremely low air permeability (0.4 cu. ft./sq. ft./min.). This characteristic is highly desirable and represents a marked improvement over caribou.

Arctic clothing, as exemplified by Eskimo clothing, differs in two main respects from temperate clothing, namely, in its greater thickness, and in the occurrence of frost within the boundaries of the clothing.

The thickness of Eskimo clothing is required to provide the necessary thermal insulation but the means by which the necessary thickness is achieved differs radically from the measures taken for the same purpose, in temperate clothing. In temperate clothing, the thickness determines to some extent the stiffness of the fabric and the individual has become accustomed to and tolerant of the restrictions inherent in the design and the materials involved since the forces involved are relatively low in proportion to the energy available to the individual. However, in

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bending clothing, the bending stress formulae are found generally to apply, so that,

$$Mb = \frac{El}{C}$$

where

Mb =bending moment,

E =modulus of elasticity,

I =moment of inertia,

C =radius of curvature to which the neutral axis is flexed.

While the forces at play are relatively inconsequential in temperate clothing, they become appreciable when the thickness of the clothing approaches the order of two inches, as the magnitude of the moment of inertia varies as the cube of the distance between the extreme fibres. Although temperate clothing is usually made up of at least two layers, thereby diminishing the forces involved by slip between the layers, slip is most resisted where most required, namely, in the area of the joints, so that the extreme outward fibres may be placed under considerable tension. The mechanical moment so induced is proportional to the tensile stress multiplied by the thickness of the material which becomes an appreciable factor in the utility of temperate clothing.

The design principle employed in temperate clothing is not, therefore, satisfactory for polar region clothing as the restrictive forces increase as an appreciable power of the thickness involved. If possible, the forces involved should be relatively independent of the thickness and should be a minimum value, well within the tolerance levels.

The foregoing criterion is achieved in Eskimo clothing consisting of two caribou skins worn back-to-back. In this assembly only the two skins themselves offer resistance to bending and the distance between the extreme fibres of these skins relative to the overall thickness of the insulation, is comparatively small. On the outer side of the parka assembly, the hair offers no resistance to bending as the fibres tend merely to separate slightly. On the inner parka the hair is compressed to some extent but the force required is relatively small. Furthermore, since the hair of the inner parka faces the wearer, the space between the wearer's skin and the skin of the inner parka is filled with soft resilient hair which is readily compressed thereby allowing freedom of movement to the joints without restriction.

Notwithstanding the desirable properties of caribou clothing, it is difficult to remove frost from caribou hair without damage to the hide, since caribou guard hair does not possess the requisite tensile strength. Frost removal is, however, essential since the moisture exuded from the body is not all carried away by convection currents next to the wearer's skin to escape by way of various openings; much of this moisture permeates the inner parka and this moisture eventually passes through the inner parka where it reaches turbulent currents of air between the inner and outer parkas. When the wearer retires to a sleeping bag at night after shedding his clothing, his parka freezes and the frost must be beaten out in the morning before it can be put on. Nevertheless, the assembly of caribou skins, back-to-back has, until now, provided body clothing of otherwise excellent characteristics,

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the back-to-back assembly serving to give more than mere freedom of movement.

The improved pile fabrics of the invention enable full advantage to be taken of the known Eskimo type of back-to-back assembly without the disadvantages hitherto attending the use of caribou skins, and enables other advantages to be gained.

Referring now to the accompanying drawings, as shown in Figure 4, the body clothing consists of an upper inner parka 21 covering the head, arms and torso and extending to about the crotch. The head covering consists of an integral hood 22 provided with a narrow face opening which hood is fairly close-fitting, and particularly so around the face. Inner pants 23 cover the body from the waist downwards (as shown in dotted lines in Figure 4) and extend approximately to the ankles. The skirt of the inner parka 21 is worn outside the inner pants 23. The parka 21 and pants 23 may conveniently be made from a pile fabric as set forth in Example III, IV or V hereof and the pile should be turned towards the skin of the wearer.

The skirt of the parka 21, as well as the ends of the sleeves and the face-opening of the hood 22 are each trimmed with ruffs comprising a pile fabric as herein described and having a pile comparable with that of wolverine fur or longer. Pile fabric as described in Example II, III, IV or V hereof but having a pile length of about 3 inches may conveniently be used for the ruffs 24, 25 and 26.

The outer garments of the body clothing are shown in Figure 5 and comprise an outer parka 27 covering the head, arms and torso and extending again to about the crotch. As in the inner parka, the head covering is integral with the parka 27 and is provided with a narrow face opening trimmed with a ruff 28 consisting, for example, of a pile fabric as set forth in Example I, II, III, IV or V but having a pile length of the order of 4 inches. Outer pants 29 are also provided extending from the waist downwards terminating slightly below the top of mukluks 30 so as to provide a short portion which may be tucked inside the mukluks. The outer parka 27 and pants 29 may conveniently be made from a pile fabric as described in Example III, IV or V hereof and the pile should be turned outwards as shown.

The clothing is completed by mitts 31 which may consist of back-to-back layers of the $\frac{3}{8}$ " fabrics of Example III, IV or V or of a single layer of such pile fabric, pile outwards worn over duffle mitts and a foot covering consisting of felt insoles, duffle socks, duffle vamps all covered by the mukluks 30 which consist of a single layer, pile outwards of the pile fabric of Example III, IV or V joined integrally with a flexible moccasins-like shoe portion 32 made, for example, of moosehide or other flexible dry-tanned good quality leather giving a good wearing surface.

The inner and outer garments should be relatively loose-fitting to maintain an appreciable air space between the inner and outer garments. The inner and outer parkas, therefore, provide elongated bell-shaped insulation around the body with ventilation from the bottom or skirt controlled by the degree of activity of the wearer. Due to the difference in specific gravity between the warm air next to the body and the outside air, the warm air remains within the parka system in spite of the open bottom to the skirts. The back-to-back assembly produces a remark-

ably flexible body clothing with high insulating qualities and good frost-removal characteristics.

No inner and outer boundary layer of cloth is necessary in this system (no other clothing need be worn beneath the inner garments) and a low weight and a low apparent bulk of body clothing can thus be secured combined with high flexibility. If insulating qualities and air and vapour permeability are maintained at the necessary levels, the most important considerations in polar clothing are bulk, flexibility and weight, and clothing as described with reference to Figures 4 and 5 satisfies all three criteria.

The marginal utility of men operating in the extreme cold of the polar regions is low under the best conditions. Hitherto, no textile fabric clothing has been devised which could be worn for long periods under polar climatic conditions approaching the utility of Eskimo clothing. Body clothing constructed as described with reference to Figures 4 and 5 has, however, been worn by Eskimos in the Arctic and has been declared by them to be as good as their traditional caribou clothing.

A number of field tests have been made in the Arctic with body clothing made from pile fabric according to Examples III, IV and V for various periods under various conditions of activity, and at exposures down to -55°F . and with wind velocities up to 50 M. P. H. Representative results obtained with one subject over several days are set forth in Tables 4, 5 and 6 below.

In these tests, skin temperatures were measured by way of copper-constantan thermocouples

supported on an elastic harness. The couples terminated in a socket on the clothing and could be connected, when required, to a plug joined by leads which extended into a warmed room housing the measuring equipment. Under the conditions of the tests, the skin temperature measurements were not accurate to more than about $\pm 1^{\circ}\text{F}$. since it was difficult to keep thermocouples in contact with the skin and the subject had to keep comparatively still while the measurements are made which inactivity allowed him to cool a little. However, the figures show the general trend of the temperature under the clothes and are lower, not higher than the true skin temperatures. It is to be noted that certain of the temperature figures are for the thermocouples next to the skin and others are for thermocouples just outside the underclothing.

A typical experiment was as follows: The subject dressed after all his clothing had been weighed, first putting on the thermocouple harness either next to his skin or over his underclothes. When completely dressed his total weight was measured. He then performed some task, such as dragging a loaded sled from a known distance. At the end of this work his skin temperatures were measured and he was reweighed and his observations concerning the clothing were recorded. By these means, data were collected regarding the warmth of the clothing under various conditions (Table 4), the changes in weight from day to day (Tables 5A and 5B) and the overall change in weight during the tests (Table 6).

TABLE 4

Subject: A.
Clothing:
Baladava, woolen.
Inner and outer parkas, Eskimo style, $\frac{3}{4}$ " nylon pile (Example V).
Inner and outer pants, Eskimo style, $\frac{3}{4}$ " nylon pile (Example V).
Flannelette pyjama tops. Army braces.
Felt insoles. Duffle socks. Duffle vamps. Canvas mukluks, with moosehide soles. Duffle mitts. Nylon pile mitts.
Thermocouple harness.

Date and Weather.	Activity.	Temperatures in clothing ($^{\circ}\text{F}$)	Comfort during Test
10 Feb. Clear with good visibility. -29°F . Wind SE 16 mph.	Light exercise walking down and into wind over snow-covered ice on lake.	(Thermocouples outside pyjama tops). Back of neck..... 76 Left arm-pit..... 90 Back..... 70 Stomach..... 63 (Thermocouples outside pyjama tops). Back of neck..... 83 Left arm-pit..... 93 Back..... 76 Stomach..... 67	Comfortable in general, but back cool. Hands and feet warm. Fingertips cool. Face cold when walking into wind.
11 Feb. -26°F . Light wind. Clear and sunny.	Medium work. Shovelling hard-packed snow for $2\frac{1}{2}$ hours.	(Thermocouples outside pyjama tops). Back of neck..... 80 Left arm-pit..... 85 Stomach..... 63 Kidneys..... 73 Weather conditions prevented thermocouple measurements.	Comfortable. No draughts anywhere. Hands and feet warm.
12 Feb. -12°F . Wind S. 16 mph. Clear.	Hard work. Pulling heavily loaded sled over level but rough ice and snow surface.	(Thermocouples outside pyjama tops). Back of neck..... 81 Left arm-pit..... 89 Stomach..... 65 Kidneys..... 84	Warm and sweating while working. No draughts except when standing waiting for T. C. measurements. Hands sweating.
15 Feb. -18°F . Wind N. 29 mph. Clear sky.	Cross country walk over hilly country for 2 hrs.	(Thermocouple harness over pyjama tops) Back of neck..... 81 Left arm-pit..... 89 Stomach..... 65 Kidneys..... 84	Warm at all times. Hands and feet warm. Froze tip of nose.
16 Feb. -19°F . Wind N. 26 mph. Clear sky. Driving snow.	Light exercise. Walking on airstrip.	(Thermocouple harness over pyjama tops) Back of neck..... 72 Left arm-pit..... 92 Back..... 92 Stomach..... 94	Comfortable in first part of exercise. Cool on second part. Froze side of nose.
17 Feb. -17°F . Wind NW. 30 mph. Driving snow.	Working at clearing snow around igloo.	(Thermocouple harness next to body) Back of neck..... 72 Left arm-pit..... 92 Back..... 92 Stomach..... 94	Comfortable generally. Face cold. Eyelashes froze together at times. Feet warm. Hands warm except thumb where pile is compressed by shovel handle.
19 Feb. -42°F . Wind N. Light. Bright and clear.	Walk over hilly country to visit traplines, approx. 4 hours walk.	(Thermocouple harness next to skin). Back of neck..... 77 Left arm-pit..... 94 Back..... 87 Stomach..... 76	Comfortable walking. Hands and feet warm. Nose froze 5 times during the walk. Body cooled rapidly when standing still at traps.
20 Feb. -31°F . Wind light. Bright and clear.	Pulled sledge loaded to 80 lbs. over rough snow for 5 miles. Tried to keep below sweating level.		Very comfortable. Feet warm but sore because of ill-fitting insoles. Hands too warm. Hoar frost appeared on pile.

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TABLE 5A

Changes in weights of clothing during test

SUBJECT: A

Date	10 Feb.	11 Feb.	12 Feb.	15 Feb.	16 Feb.
Garments (Weights in grams):					
Inner and outer parkas	3,000	3,000	2,950	2,950	3,075
Inner and outer pants	1,920	1,930	1,910	1,910	1,960
Pyjama tops	285		290		280
Insoles					
Duffle socks	610	610	600	696	605
Duffle vamps					
Mukluks	380	400	420	460	495
Duffle mitts	300	335			330
Pile mitts					
Athletic support	77		77		
Balaclava		108	118		120
Man and Garments (in lbs. and ozs.):					
Before test	183/3	182/5	182/7		180/11
After test	183/3	182/5	181/1		

TABLE 5B

Changes in weights of clothing during test

SUBJECT: A (Continued)

Date	17 Feb.	19 Feb.	20 Feb.
Garments (weights in grams):			
Inner and outer parkas	3,100	3,150	3,100
Inner and outer pants	1,970	1,965	1,955
Pyjama tops		290	
Insoles			
Duffle socks	615		480
Duffle vamps			
Mukluks			370
Duffle mitts	500	395 (new)	400
Pile mitts	340		335
Balaclava		125	
Woolen gloves			
Man and Garments:			
Before test		179/12	177/13
After test		179/13	177/2

TABLE 6

[Clothes were worn from February 8 to 21. They were then doffed and weighed. Later they were room dried and reweighed.]

SUBJECT: A

Weights in grams

Articles	Damp	Dry
Inner parka	1,515	1,440
Outer parka	1,575	1,475
Inner pants	880	865
Outer pants	975	950
Insoles	80	
Duffle socks	410	385
Vamps		
Mukluks	315	
Mukluks	435	325
Duffle and Pile mitts	340	265

The low air-permeability of the fabrics in accordance with the invention leads to outstanding uniformity of temperature within the suiting; this fact was strikingly demonstrated during early field tests by one subject who wore a suit of fabric according to Example IV but in which the rubber bonding agent was inadvertently insufficient so giving rise to a highly permeable fabric. This observer was forced to take shelter after 15 minutes exposure; on the other hand a similar suit with fabric of the required air permeability was very warm while walking at a wind chill of 2300 kg. cal./sq. m./hour, expressed in terms of the Wind Chill Tables appearing for example in "Measurements of Dry Atmospheric Cooling in Sub-Freezing Temperatures" by Siple and Passel, Proceedings of American Philosophical Society, vol. 89, No. 1, 1945.

From our tests we conclude that the pile fabric of the invention made into Eskimo type clothing

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is adequate for survival under the worst conditions encountered. Under somewhat milder conditions, the wearer would be able to work in relative comfort even though the total weight of the clothing is only about 14 lbs.

Moisture accumulation in the clothing worn for long periods is not considered to be serious. The high water vapour permeability of the fabric was clearly shown by the collection of hoarfrost on the outer pile hairs when the wearer was working hard, pointing to the fact that a considerable amount of water vapour had passed completely through the fabric layers.

It is necessary, of course, to give the clothing more care than is customary in normal, temperate region, life. Thus, snow and frost should always be beaten out of the garments and ice should be removed from the parka ruff after wear. If this is done, and the outer garment hung up to dry, quite considerable drying can occur even in the conditions inside a snow-house with a maximum air temperature of around +25° F.

The field tests have proved satisfactory in all respects and demonstrate that polar clothing constructed as described above of pile fabric of Examples III, IV and V with pile lengths ranging from ¼ to ¾ inches provides the required thermal protection to the wearer with minimum bulk and stiffness and combines the best features of caribou with those of wolverine and results in clothing which is superior in performance to any cold weather suiting yet devised. A saving in weight of ten pounds has been achieved over non-native clothing of limited comparable performance with a remarkable improvement in flexibility.

What we claim as our invention is:

1. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible ground cloth of interlaced yarns and a pile surface having substantially smooth-surfaced artificial filaments anchored in interlaced relationship thereto, said filaments having a denier per filament within the range of about 10 to 75 and being flexible at and retaining their strength at the sub-zero temperatures obtaining under polar conditions, and having a tensile strength per filament greater than about 1.36 gms. per denier and exhibiting low moisture absorption at high relative humidities, said pile fabric having a structure modified from the original to provide pores to give to the fabric a low air transmission rate less than substantially 10 cubic feet per square foot per minute at ½ inch water pressure differential.

2. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible woven ground cloth and a pile surface having substantially smooth-surfaced artificial filaments anchored thereto in interlaced relationship, said filaments having a denier per filament within the range of about 10 to 75 and being flexible at and retaining their strength at the sub-zero temperatures obtaining under polar conditions, and having a tensile strength per filament greater than about 1.36 gms. per denier and exhibiting low moisture absorption at high relative humidities, the filaments of said pile surface having a minimum free length of approximately ¼ inch, said fabric having a structure modified from the original to provide pores to give to the fabric a low air transmission rate less than substantially 10 cubic feet per square foot per minute at ½ inch water pressure differential.

3. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible woven ground cloth and a pile surface having substantially smooth-surfaced artificial filaments anchored thereto, said filaments having a denier per filament within the range of about 10 to 75 and being flexible at and retaining their strength at the sub-zero temperatures obtaining under polar conditions, and having a tensile strength per filament greater than about 1.36 gms. per denier and exhibiting low moisture absorption at high relative humidities, the filaments of said pile surface having a minimum free length of approximately $\frac{1}{8}$ inch, said fabric having a structure modified from the original to provide pores to give the fabric a low air transmission rate less than substantially 10 cubic feet per square foot per minute at $\frac{1}{2}$ inch water pressure differential, said fabric having a low overall bulk density calculated at less than about 5.0 lbs. per cubic foot.

4. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible woven ground cloth and a pile surface having substantially smooth-surfaced artificial filaments anchored in woven relationship thereto, said filaments having a denier per filament within the range of about 10 to 75 and being flexible at and retaining their strength at the sub-zero temperatures obtaining under polar conditions, and having a tensile strength per filament greater than about 1.36 gms. per denier and exhibiting low moisture absorption at high relative humidities, the filaments of said pile surface having a minimum free length of approximately $\frac{1}{8}$ inch, said fabric having a structure modified from the original to provide pores to give to the fabric a low air transmission rate less than substantially 10 cubic feet per square foot per minute at $\frac{1}{2}$ inch water pressure differential and a high water vapor transmission rate greater than approximately 20 gms. per square meter per hour at 10 mms. water vapor pressure differential measured at body temperatures at one side and at 0° C. on the other side of the fabric, said fabric having a low overall bulk density calculated at less than about 5.0 lbs. per cubic foot.

5. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible woven ground cloth and a pile having substantially smooth-surfaced straight artificial filaments anchored in woven relationship thereto, said filaments having a denier per filament within the range of about 10 to 75 and being flexible at and retaining their strength at the sub-zero temperatures obtaining under polar conditions, and having a tensile strength per filament greater than about 1.36 gms. per denier and exhibiting low moisture absorption at high relative humidities, the filaments of said pile having a minimum free length of approximately $\frac{1}{8}$ inch, said pile having a number of such filament ends per square inch given by the quotient of the expression k/d where k has a value between 200,000 and 300,000 and where d is the denier of the filaments, said fabric having a structure modified from the original to provide pores to give to the fabric a low air transmission rate less than substantially 10 cubic feet per square foot per minute at $\frac{1}{2}$ inch water pressure differential.

6. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible woven ground cloth and a pile having substantially smooth-surfaced straight nylon filaments anchored in woven relationship thereto, said fila-

ments having a denier per filament within the range of about 10 to 75, the filaments of said pile surface having a minimum free length of approximately $\frac{1}{8}$ inch, said pile having a number of such filament ends per square inch given by the quotient of the expression k/d where k has a value between 200,000 and 300,000 and where d is the denier of the filaments, said fabric having pores to give to the fabric a low air transmission rate less than substantially 10 cubic feet per square foot per minute at $\frac{1}{2}$ inch water pressure differential.

7. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible ground cloth and a pile surface having substantially smooth-surfaced artificial filaments anchored thereto, said filaments having a denier per filament within the range of about 10 to 75 and being flexible at and retaining their strength at the sub-zero temperatures obtaining under polar conditions, and having a tensile strength per filament greater than about 1.36 gms. per denier and exhibiting low moisture absorption at high relative humidities, the filaments of said pile surface having a minimum free length of approximately $\frac{1}{8}$ inch, said fabric having a structure modified from the original to provide pores to give to the fabric a low air transmission rate less than substantially 10 cubic feet per square foot per minute at $\frac{1}{2}$ inch water pressure differential, the pile surface of said fabric consisting of filaments selected from the group comprising, the polymeric amides known generally as nylon, vinyl resins, vinylidenes chloride polymers and polyacrylonitrile.

8. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible ground cloth and a pile surface having substantially smooth-surfaced artificial filaments having a denier per filament within the range of about 10 to 75 and being flexible at and retaining their strength at the sub-zero temperatures obtaining under polar conditions, and having a tensile strength per filament greater than about 1.36 gms. per denier and exhibiting low moisture absorption at high relative humidities, the filaments of said pile having a minimum free length of approximately $\frac{1}{8}$ inch, the pile filaments being anchored to the ground cloth by a bonding agent, the finished fabric having pores providing a low air transmission rate less than substantially 10 cubic feet per square foot per minute at a $\frac{1}{2}$ inch water pressure differential.

9. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible ground cloth and a pile surface having substantially smooth-surfaced artificial filaments having a denier per filament within the range of about 10 to 75 and being flexible at and retaining their strength at the sub-zero temperatures obtaining under polar conditions, and having a tensile strength per filament greater than about 1.36 gms. per denier and exhibiting low moisture absorption at high relative humidities, the filaments of said pile having a minimum free length of approximately $\frac{1}{8}$ inch, the pile filaments being anchored to the ground cloth by a bonding agent, the finished fabric having pores providing a low air transmission rate less than substantially 10 cubic feet per square foot per minute at a $\frac{1}{2}$ inch water pressure differential, and a minimum water vapor transmission per square meter per hour of 20 gms. at a vapor pressure differential of 10 mm. of mercury meas-

ured at body temperatures at one side and 0° C. on the other side of the fabric.

10. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible ground cloth of woven nylon filament yarn and a pile having substantially smooth-surfaced straight nylon filaments anchored in woven relationship to said ground cloth, said filaments of said pile having a denier per filament within the range of about 10 to 75 and having a minimum free length of approximately $\frac{1}{8}$ inch, said pile having a number of such filament ends per square inch given by the quotient of the expression k/d where k is the value between 200,000 and 300,000 and where d is the denier of the filaments, the ground cloth having a rubber bonding agent deposited on the back thereof, the bonding agent being present in an amount not exceeding approximately one ounce dried weight per square yard of fabric, the finished fabric with pores providing a low air transmission rate less than substantially 10 cubic feet per square foot per minute at $\frac{1}{2}$ inch water pressure differential, and a minimum water vapor transmission per square meter per hour of 20 gms. at a vapor pressure differential of 10 mm. of mercury measured at body temperatures at one side and 0° C. on the other side of the fabric, said fabric having a low overall bulk density calculated at less than about 5.0 lbs. per cubic foot.

11. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible ground cloth of woven textile fabric and a pile having substantially smooth-surfaced straight nylon filaments anchored in woven relationship thereto, said filaments having a denier per filament within the range of about 10 to 75 and having a free length ranging approximately from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch, said pile having a number of such filament ends per square inch given by the quotient of the expression k/d where k has a value

between 200,000 and 300,000 and where d is the denier of the filaments, the finished fabric having a structure modified from the original to provide pores to give to the fabric a low air transmission rate less than substantially 10 cubic feet per square foot per minute at a $\frac{1}{2}$ inch water pressure differential.

12. A lightweight flexible pile fabric for cold weather clothing comprising, a flexible ground cloth of woven textile fabric, and a pile surface having substantially smooth-surfaced straight nylon filaments anchored thereto in woven relationship, said filaments having a denier per filament within the range of about 10 to 75 and having a free length of approximately $1\frac{1}{8}$ inches, said pile filaments being anchored to the ground cloth by a rubber bonding agent deposited over the back of the ground cloth to bond the pile filaments to the woven textile fabric of the ground cloth, the fabric thus modified having a structure with pores to give to the fabric a low transmission rate less than substantially 10 cubic feet per square foot per minute at $\frac{1}{2}$ inch water pressure differential.

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