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Groups

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Summary. Notions of group and abelian group are introduced. The power of an element of a group, order of group and order of an element of a group are defined. Basic theorems concerning those notions are presented.

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The articles [13], [6], [17], [14], [18], [4], [9], [5], [16], [10], [15], [2], [7], [12], [1], [8], [3], and [11] provide the notation and terminology for this paper.

For simplicity, we use the following convention: m, n are natural numbers, i, j are integers, S is a non empty groupoid, and r, s, s_1, s_2, t are elements of S.

Let i be an integer. Then $|i|$ is a natural number.

Let A be a non empty set and let m be a binary operation on A. One can check that $\langle A, m\rangle$ is non empty.

Let I_1 be a non empty groupoid. We say that I_1 is unital if and only if:

(Def. 1) There exists an element e of I_1 such that for every element h of I_1 holds $h \cdot e = h$ and $e \cdot h = h$.

We say that I_1 is group-like if and only if the condition (Def. 3) is satisfied.

(Def. 3)[1] There exists an element e of I_1 such that for every element h of I_1 holds $h \cdot e = h$ and $e \cdot h = h$ and there exists an element g of I_1 such that $h \cdot g = e$ and $g \cdot h = e$.

Let us observe that every non empty groupoid which is group-like is also unital.

One can check that there exists a non empty groupoid which is strict, group-like, and associative.

A group is a group-like associative non empty groupoid.

The following propositions are true:

(5)[2] Suppose for all r, s, t holds $(r \cdot s) \cdot t = r \cdot (s \cdot t)$ and there exists t such that for every s_1 holds $s_1 \cdot t = s_1$ and $t \cdot s_1 = s_1$ and there exists s_2 such that $s_1 \cdot s_2 = t$ and $s_2 \cdot s_1 = t$. Then S is a group.

(6) Suppose for all r, s, t holds $(r \cdot s) \cdot t = r \cdot (s \cdot t)$ and for all r, s holds there exists t such that $r \cdot t = s$ and there exists t such that $t \cdot r = s$. Then S is associative and group-like.

(7) $\langle \mathbb{R}, +_{\mathbb{R}} \rangle$ is associative and group-like.

In the sequel G denotes a group-like non empty groupoid and e, h denote elements of G.

Let G be a unital non empty groupoid. The functor 1_G yielding an element of G is defined as follows:

[1] The definition (Def. 2) has been removed.
[2] The propositions (1)–(4) have been removed.

(Def. 4) For every element h of G holds $h \cdot 1_G = h$ and $1_G \cdot h = h$.

The following proposition is true

(10)[3] If for every h holds $h \cdot e = h$ and $e \cdot h = h$, then $e = 1_G$.

In the sequel G denotes a group and f, g, h denote elements of G.
Let us consider G, h. The functor h^{-1} yielding an element of G is defined as follows:

(Def. 5) $h \cdot h^{-1} = 1_G$ and $h^{-1} \cdot h = 1_G$.

The following propositions are true:

(12)[4] If $h \cdot g = 1_G$ and $g \cdot h = 1_G$, then $g = h^{-1}$.

(14)[5] If $h \cdot g = h \cdot f$ or $g \cdot h = f \cdot h$, then $g = f$.

(15) If $h \cdot g = h$ or $g \cdot h = h$, then $g = 1_G$.

(16) $(1_G)^{-1} = 1_G$.

(17) If $h^{-1} = g^{-1}$, then $h = g$.

(18) If $h^{-1} = 1_G$, then $h = 1_G$.

(19) $(h^{-1})^{-1} = h$.

(20) If $h \cdot g = 1_G$ or $g \cdot h = 1_G$, then $h = g^{-1}$ and $g = h^{-1}$.

(21) $h \cdot f = g$ iff $f = h^{-1} \cdot g$.

(22) $f \cdot h = g$ iff $f = g \cdot h^{-1}$.

(23) There exists f such that $g \cdot f = h$.

(24) There exists f such that $f \cdot g = h$.

(25) $(h \cdot g)^{-1} = g^{-1} \cdot h^{-1}$.

(26) $g \cdot h = h \cdot g$ iff $(g \cdot h)^{-1} = g^{-1} \cdot h^{-1}$.

(27) $g \cdot h = h \cdot g$ iff $g^{-1} \cdot h^{-1} = h^{-1} \cdot g^{-1}$.

(28) $g \cdot h = h \cdot g$ iff $g \cdot h^{-1} = h^{-1} \cdot g$.

Let us consider G. The functor $\cdot_G^{-1}$ yields a unary operation on the carrier of G and is defined by:

(Def. 6) $\cdot_G^{-1}(h) = h^{-1}$.

Next we state several propositions:

(31)[6] For every associative non empty groupoid G holds the multiplication of G is associative.

(32) For every unital non empty groupoid G holds 1_G is a unity w.r.t. the multiplication of G.

(33) For every unital non empty groupoid G holds $\mathbf{1}_{\text{the multiplication of } G} = 1_G$.

(34) For every unital non empty groupoid G holds the multiplication of G has a unity.

(35) $\cdot_G^{-1}$ is an inverse operation w.r.t. the multiplication of G.

[3] The propositions (8) and (9) have been removed.
[4] The proposition (11) has been removed.
[5] The proposition (13) has been removed.
[6] The propositions (29) and (30) have been removed.

(36) The multiplication of G has an inverse operation.

(37) The inverse operation w.r.t. the multiplication of $G = \cdot_G^{-1}$.

Let G be a unital non empty groupoid. The functor power_G yielding a function from $[:$the carrier of G, $\mathbb{N}:]$ into the carrier of G is defined by:

(Def. 7) For every element h of G holds $\mathrm{power}_G(h, 0) = 1_G$ and for every n holds $\mathrm{power}_G(h, n+1) = \mathrm{power}_G(h, n) \cdot h$.

Let us consider G, i, h. The functor h^i yields an element of G and is defined by:

(Def. 8) $h^i = \begin{cases} \mathrm{power}_G(h, |i|), & \text{if } 0 \leq i, \\ \mathrm{power}_G(h, |i|)^{-1}, & \text{otherwise.} \end{cases}$

Let us consider G, n, h. Then h^n can be characterized by the condition:

(Def. 9) $h^n = \mathrm{power}_G(h, n)$.

Next we state a number of propositions:

(42)[7] $(1_G)^n = 1_G$.

(43) $h^0 = 1_G$.

(44) $h^1 = h$.

(45) $h^2 = h \cdot h$.

(46) $h^3 = h \cdot h \cdot h$.

(47) $h^2 = 1_G$ iff $h^{-1} = h$.

(48) $h^{n+m} = h^n \cdot h^m$.

(49) $h^{n+1} = h^n \cdot h$ and $h^{n+1} = h \cdot h^n$.

(50) $h^{n \cdot m} = (h^n)^m$.

(51) $(h^{-1})^n = (h^n)^{-1}$.

(52) If $g \cdot h = h \cdot g$, then $g \cdot h^n = h^n \cdot g$.

(53) If $g \cdot h = h \cdot g$, then $g^n \cdot h^m = h^m \cdot g^n$.

(54) If $g \cdot h = h \cdot g$, then $(g \cdot h)^n = g^n \cdot h^n$.

(55) If $0 \leq i$, then $h^i = h^{|i|}$.

(56) If $0 \not\leq i$, then $h^i = (h^{|i|})^{-1}$.

(59)[8] If $i = 0$, then $h^i = 1_G$.

(60) If $i \leq 0$, then $h^i = (h^{|i|})^{-1}$.

(61) $(1_G)^i = 1_G$.

(62) $h^{-1} = h^{-1}$.

(63) $h^{i+j} = h^i \cdot h^j$.

(64) $h^{n+j} = h^n \cdot h^j$.

(65) $h^{i+m} = h^i \cdot h^m$.

[7] The propositions (38)–(41) have been removed.
[8] The propositions (57) and (58) have been removed.

(66) $h^{j+1} = h^j \cdot h$ and $h^{j+1} = h \cdot h^j$.

(67) $h^{i \cdot j} = (h^i)^j$.

(68) $h^{n \cdot j} = (h^n)^j$.

(69) $h^{i \cdot m} = (h^i)^m$.

(70) $h^{-i} = (h^i)^{-1}$.

(71) $h^{-n} = (h^n)^{-1}$.

(72) $(h^{-1})^i = (h^i)^{-1}$.

(73) If $g \cdot h = h \cdot g$, then $(g \cdot h)^i = g^i \cdot h^i$.

(74) If $g \cdot h = h \cdot g$, then $g^i \cdot h^j = h^j \cdot g^i$.

(75) If $g \cdot h = h \cdot g$, then $g^n \cdot h^j = h^j \cdot g^n$.

(77)[9] If $g \cdot h = h \cdot g$, then $g \cdot h^i = h^i \cdot g$.

Let us consider G, h. We say that h is of order 0 if and only if:

(Def. 10) If $h^n = 1_G$, then $n = 0$.

We introduce h is of order 0 as a synonym of h is of order 0. We introduce h is not of order 0 as an antonym of h is of order 0.

One can prove the following proposition

(79)[10] 1_G is not of order 0.

Let us consider G, h. The functor $\mathrm{ord}(h)$ yielding a natural number is defined as follows:

(Def. 11)(i) $\mathrm{ord}(h) = 0$ if h is of order 0,

(ii) $h^{\mathrm{ord}(h)} = 1_G$ and $\mathrm{ord}(h) \neq 0$ and for every m such that $h^m = 1_G$ and $m \neq 0$ holds $\mathrm{ord}(h) \leq m$, otherwise.

Next we state four propositions:

(82)[11] $h^{\mathrm{ord}(h)} = 1_G$.

(84)[12] $\mathrm{ord}(1_G) = 1$.

(85) If $\mathrm{ord}(h) = 1$, then $h = 1_G$.

(86) If $h^n = 1_G$, then $\mathrm{ord}(h) \mid n$.

Let us consider G. The functor $\mathrm{Ord}(G)$ yielding a cardinal number is defined by:

(Def. 12) $\mathrm{Ord}(G) = \overline{\overline{\text{the carrier of } G}}$.

Let S be a 1-sorted structure. We say that S is finite if and only if:

(Def. 13) The carrier of S is finite.

We introduce S is infinite as an antonym of S is finite.

Let us consider G. Let us assume that G is finite. The functor $\mathrm{ord}(G)$ yields a natural number and is defined as follows:

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[9] The proposition (76) has been removed.
[10] The proposition (78) has been removed.
[11] The propositions (80) and (81) have been removed.
[12] The proposition (83) has been removed.

(Def. 14) There exists a finite set B such that $B =$ the carrier of G and $\mathrm{ord}(G) = \mathrm{card}\, B$.

One can prove the following proposition

(90)[13] If G is finite, then $\mathrm{ord}(G) \geq 1$.

One can verify that there exists a group which is strict and commutative.

One can prove the following proposition

(92)[14] $\langle \mathbb{R}, +_{\mathbb{R}} \rangle$ is a commutative group.

In the sequel A denotes a commutative group and a, b denote elements of A.

The following three propositions are true:

(94)[15] $(a \cdot b)^{-1} = a^{-1} \cdot b^{-1}$.

(95) $(a \cdot b)^n = a^n \cdot b^n$.

(96) $(a \cdot b)^i = a^i \cdot b^i$.

Let A be a non empty set, let m be a binary operation on A, and let u be an element of A. One can check that $\langle A, m, u \rangle$ is non empty.

The following proposition is true

(97) $\langle$the carrier of A, the multiplication of A, $1_A\rangle$ is Abelian, add-associative, right zeroed, and right complementable.

In the sequel B denotes an Abelian group.

We now state the proposition

(98) $\langle$the carrier of B, the addition of $B\rangle$ is a commutative group.

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