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# Notation

ZF	Zermelo-Fraenkel axiomatic theory	3
ZFC	the theory ZF with the Axiom of Choice	3
$x \in y, x = y$	atomic formulas: $x$ is a member of $y$ , $x$ is equal to $y$	5
$\wedge, \vee, \neg, \rightarrow, \leftrightarrow$	logical connectives: conjunction, disjunction, negation, implication, equivalence	5
$\forall x, \exists x$	quantifiers: for all $x$ , there exists $x$	5
$\{x : \varphi(x, p_1, \dots, p_n)\}$	the class of all $x$ satisfying $\varphi(x, p_1, \dots, p_n)$	5
$C = D$	a class $C$ is equal to a class $D$	5
$V$	universal class (universe, $\{x : x = x\}$ )	6
$C \subset D$	a class $C$ is included in a class $D$	6
$C \cap D$	the intersection of classes $C$ and $D$	6
$C \cup D$	the union of classes $C$ and $D$	6
$C - D$	the difference of classes $C$ and $D$	6
$\bigcup C$	the union of sets from a class $C$	6
$\{a, b\}$	the pair	7
$\{a\}$	the singleton	7
$(a, b)$	the ordered pair	7
$(a_1, \dots, a_{n+1})$	the ordered $n + 1$ -tuple	7
$\emptyset$	the empty set	8
$\bigcap C$	the intersection of sets from a class $C$	8
$\bigcup X$	the union	9
$\{a_1, \dots, a_n\}$	the set with elements $a_1, \dots, a_n$	9
$X \Delta Y$	symmetric difference of $X$ and $Y$	9
$P(X)$	the power set of $X$	9
$X \times Y$	the product of $X$ and $Y$	10
$X_1 \times \dots \times X_{n+1}$	the product of $n + 1$ sets	10
$X^n$	the power of a set $X$	10
$\text{dom}(R)$	the domain of a relation $R$	10
$\text{ran}(R)$	the range of a relation $R$	10
$\text{field}(R)$	the field of a relation $R$	10
$y = f(x)$	$y$ is the value of $f$ at $x$	11
$f : X \rightarrow Y$	$f$ is a function from $X$ to $Y$	11
$Y^X$	the set of functions from $X$ to $Y$	11
$f \upharpoonright X$	the restriction of a function $f$ to a set $X$	11
$f \circ g$	composition of $f$ and $g$	11
$f \text{``} X, f(X)$	the image of a set $X$ by a function $f$	11
$f^{-1}(X)$	the inverse image of a set $X$ by a function $f$	11
$f^{-1}$	the inverse of a function $f$	11
$F \text{``} C, F(C)$	the image of a class $C$ by a class function $F$	12
$[x]$	the equivalence class of $x$	12
$X/\equiv$	the quotient of $X$ by an equivalence relation $\equiv$	12

$\mathbf{N}$	the smallest inductive set	13
$0, 1, 2, 3, \dots$	the natural numbers	13
$(P, <)$	a partially ordered set	17
$\sup X$	the supremum of $X$	17
$\inf X$	the infimum of $X$	17
$Ord$	the class of ordinals	19
$\alpha + 1$	the successor of an ordinal $\alpha$	20
$\omega, \mathbf{N}$	the set of finite ordinals (natural numbers)	20
$\langle a_\xi : \xi < \alpha \rangle$	an $\alpha$ -sequence; a (transfinite) sequence of length $\alpha$	21
$s \widehat{\ } x, sx$	the extension of a sequence $s$ by an element $x$	21
$\langle a_\alpha : \alpha \in Ord \rangle$	a sequence	21
$\lim_{\xi \rightarrow \alpha} \gamma_\xi$	the limit of a sequence $\langle \gamma_\xi : \xi < \alpha \rangle$	22
$\alpha + \beta$	the sum of ordinals $\alpha$ and $\beta$	23
$\alpha \cdot \beta$	the product of ordinals $\alpha$ and $\beta$	23
$\alpha^\beta$	the power of an ordinal $\alpha$ by an ordinal $\beta$	23
$\varepsilon_0$	the least ordinal $\alpha$ such that $\alpha = \omega^\alpha$	24
$\rho(x)$	the rank of an element $x$ in a well-founded relation $E$	25
$ X  =  Y $	sets $X, Y$ have the same cardinality	27
$ X  \leq  Y $	the cardinality of a set $X$ is less or equal to the cardinality of a set $Y$ (there exists a one-to-one mapping of $X$ into $Y$ )	27
$\kappa + \lambda$	the sum of cardinals $\kappa$ and $\lambda$	28
$\kappa \cdot \lambda$	the product of cardinals $\kappa$ and $\lambda$	28
$\kappa^\lambda$	the power of a cardinal $\kappa$ by a cardinal $\lambda$	28
$\chi_X$	the characteristic function of a subset $X$ of a given set	28
$ W $	the cardinal of a well-ordered set $W$	29
$\alpha^+$	the cardinal successor of an ordinal $\alpha$	29
$h(X)$	Hartogs function	29
$\aleph_\alpha$	the $\alpha$ th infinite cardinal	30
$\omega_\alpha$	the $\alpha$ th infinite order-type of a well-ordered set	30
$\Gamma$	the canonical well-ordering of $Ord^2$	30
$cf \alpha$	the cofinality of an ordinal $\alpha$	31
$\mathbf{R}$	the set of real numbers	37
$\mathfrak{c}$	the cardinality of the continuum (continuum)	37
$\mathbf{Q}$	the set of rational numbers	37
$\mathbf{C}$	the Cantor set	37
CH	the Continuum Hypothesis	37
$G_\delta, F_\sigma$	$G_\delta$ sets, $F_\sigma$ sets	42
$\mathcal{N}$	the Baire space ( $\omega^\omega$ )	42
$O(s)$	a basic clopen set in the Baire space	42
$Seq$	the set of finite sequences of natural numbers	43
$[T]$	the set of infinite paths through a tree $T$	43
AC	the Axiom of Choice	47
DC	the Principle of Dependent Choices	50
$[A]^\lambda$	the set of subsets of $A$ of cardinality $\lambda$	51
$[A]^{<\kappa}, P_\kappa(A)$	the set of subsets of $A$ of cardinality less than $\kappa$	52
$\sum_{i \in I} \kappa_i$	the sum of cardinal numbers $\kappa_i, i \in I$	52
$\prod_{i \in I} X_i$	the product of sets $X_i, i \in I$	53
$\prod_{i \in I} \kappa_i$	the product of cardinal numbers $\kappa_i, i \in I$	53
GCH	the Generalized Continuum Hypothesis	55
$\beth_\alpha$	the beth function	55
$\beth(\kappa)$	the gimel function ( $\kappa^{cf \kappa}$ )	56
SCH	the Singular Cardinal Hypothesis	58
TC( $S$ )	the transitive closure of a set $S$	64

$V_\alpha$	the $\alpha$ th set of the cumulative hierarchy of sets	64
$\text{rank}(x)$	the rank of a set $x$ (in the cumulative hierarchy of sets)	64
$\hat{C}$	the set of elements of a class $C$ with minimal rank	65
$[x]$	the type of an equivalence class of an equivalence relation on a proper class	65
$C/\equiv$	the quotient of a (proper) class $C$ by an equivalence relation $\equiv$	65
$\text{ext}_E(x)$	the extension of $x$ by a binary relation $E$ ( $\{z : z E x\}$ )	67
BG	Bernays-Gödel axiomatic theory	70
BGC	the theory BG with the Axiom of Choice	70
$\hat{P}$	$\{Q \in [A]^{<\omega} : P \subset Q\}$ for $P \in [A]^{<\omega}$	73
$u + u, u \cdot v, -u$	the Boolean operations: the sum, the product, and the complement	78
$[\varphi]$	the class of equivalent sentences of a first order language (member of the Lindenbaum algebra)	79
$B^+$	the set of all nonzero elements of a Boolean algebra $B$	79
$B a$	the Boolean algebra $\{u \in B : u \leq a\}$ with the partial order inherited from $B$	79
$u \Delta v$	$(u - v) + (v - u)$	80
$B/I, B/\sim$	the quotient of a Boolean algebra $B$ mod $I$	80
$\sum\{u : u \in X\}$	the supremum (sum) of a set $X$ in a Boolean algebra	82
$\prod\{u : u \in X\}$	the infimum (product) of a set $X$ in a Boolean algebra	82
$\text{sat}(B)$	the least $\kappa$ that $B$ is $\kappa$ -saturated	84
$f_*(U)$	the ultrafilter $\{X \subset T : f_{-1}(X) \in U\}$	86
$a = \lim_U a_n$	$a$ is the $U$ -limit of $a_n, n \in \omega$	86
$u \oplus v$	$(u - v) + (v - u)$	87
$\Delta_{\alpha < \kappa} X_\alpha$	the diagonal intersection of $X_\alpha, \alpha < \kappa$	92
$I_{NS}$	the nonstationary ideal	93
$\sum_{\alpha < \kappa} X_\alpha$	the diagonal union of $X_\alpha, \alpha < \kappa$	93
$E_\lambda^\kappa$	$\{\alpha < \kappa : \text{cf } \alpha = \lambda\}$	94
$\text{Tr}(S)$	the trace of a stationary set $S$	99
$\text{Lim}(C)$	the set of all limit points of a set $C$	100
$o(A)$	the order of a stationary set $A$	100
$\Delta_{a \in A} X_a$	the diagonal intersection in $P_\kappa(A)$	101
$X A$	the projection of $X \in P_\kappa(B)$ to a set $A \subset B$	102
$Y^B$	the lifting of $Y \in P_\kappa(A)$ to $B \supset A$	102
$\kappa \rightarrow (\lambda)_m^n$	$\kappa$ arrows $\lambda$	109
$\kappa \rightarrow (\alpha)_m^n$	$\kappa$ arrows $\alpha$	112
$\kappa \rightarrow (\alpha, \beta)^n$	$\kappa$ arrows $(\alpha, \beta)$	112
$o(x)$	the order-type of $\{y : y < x\}$ in a tree $T$	114
$\text{height}(T)$	the height of a tree $T, \sup\{o(x) + 1 : x \in T\}$	114
$\kappa \rightarrow (\alpha)_{<\omega}^m$	$\kappa$ arrows $\alpha$	121
$\Sigma_\alpha^0, \Pi_\alpha^0$	the hierarchy of Borel sets ( $\Sigma_\alpha^0$ sets, $\Pi_\alpha^0$ sets)	140
$\mathcal{A}\{A_s : s \in \text{Seq}\}$	Suslin operation ( $\bigcup_{a \in \omega^\omega} \bigcap_{n=0}^\infty A_{a n}$ )	143
$\Sigma_n^1, \Pi_n^1, \Delta_n^1$	the hierarchy of projective sets ( $\Sigma_n^1$ sets, $\Pi_n^1$ sets, $\Delta_n^1$ sets)	144
$\mu^*(X)$	the outer measure of a set $X$	146
$v(I)$	the volume of an interval $I$	146
$\mu(A)$	the Lebesgue measure of a set $A$	147
$t^{\mathfrak{A}}[a_1, \dots, a_n]$	the value of a term $t$ in a model $\mathfrak{A}$	155
$\mathfrak{A} \models \varphi[a_1, \dots, a_n]$	a formula $\varphi$ holds in a model $\mathfrak{A}$	155
$\mathfrak{B} \prec \mathfrak{A}$	a model $\mathfrak{B}$ is an elementary submodel of a model $\mathfrak{A}$	156
$f =_F g$	the functions $f$ and $g$ are equal modulo a filter $F$	158
$\varphi^{M,E}, \varphi^M, (M, E) \models \varphi$	the relativization of a formula $\varphi$	161

$Form$	the set of all formulas of the language $\{\in\}$	162
$\ulcorner\varphi\urcorner$	the set coding a formula $\varphi$ ( $\ulcorner\varphi\urcorner \in Form$ )	162
$\#\sigma$	the Gödel number of a sentence $\sigma$	162
$T(x)$	the truth definition	162
$H_\kappa$	the set of all $x$ with $ TC(X)  < \kappa$	171
$def(M)$	the set of subsets of $M$ definable over $(M, \in)$	175
$L_\alpha, L$	the hierarchy of constructible sets	175
$G_1, \dots, G_{10}$	Gödel operations	178
$cl(M)$	the closure of a set $M$ under Gödel operations $G_1, \dots, G_{10}$	181
$C^M$	the class $\{x : \varphi^M(x)\}$ where $C = \{x : \varphi(x)\}$	182
$F^M$	the operation $F$ defined in a class $M$	182
$c^M$	the constant $c$ defined in a class $M$	182
$\Sigma_n, \Pi_n, \Delta_n$	the hierarchy of properties, classes, relations, and functions	183
$\models_n, \models_n^M$	the satisfaction relation restricted to $\Sigma_n$ formulas	186
$M \prec_{\Sigma_n} N$	$M$ is a $\Sigma_n$ -elementary submodel of $N$	187
$<_{\alpha+1}^n$	the end-extensions of canonical well-orderings of the subsets $W_n^\alpha$ of $L_{\alpha+1}$	189
$<_{\alpha+1}$	the canonical well-ordering of $L_{\alpha+1}$	189
$<_L$	the canonical well-ordering of $L$	190
$\diamond$	the Diamond Principle	191
$def_A(M)$	the set of subsets of $M$ definable over $(M, \in, A \cap M)$	192
$L_\alpha[A], L[A]$	the hierarchy of sets constructible from a set $A$	192
$L(\mathbf{R})$	the smallest inner model that contains all reals	193
$L_\alpha(A), L(A)$	the hierarchy of sets constructible from elements of the transitive closure of a set $A$	193
$OD$	the class of ordinal-definable sets	194
$HOD$	the class of hereditarily ordinal-definable sets	194
$OD[A]$	the class of ordinal-definable sets from $A$	195
$HOD[A]$	the class of hereditarily ordinal-definable sets from $A$	195
$OD(A)$	the class of ordinal-definable sets over $A$	195
$HOD(A)$	the class of hereditarily ordinal-definable sets over $A$	196
$ZF^-$	Zermelo-Fraenkel set theory without the Power Set Axiom	198
$L[A]$	the class of sets constructible from a class $A$	199
$M[X]$	the least model of ZF such that $M \subset M[X]$ and $X \in M[X]$	199
$\dot{a}$	a name of a set from $V[G]$	203
$x \sim y$	the set of conditions compatible with $x$ in a forcing notion is the same as that for $y$	205
$Q = P/\sim$	$Q$ is the separative quotient of $P$	205
$e : P \rightarrow B(P)$	the Boolean completion of a partially ordered set $P$	206
$\ x = y\ , \ x \in y\ $	Boolean functions in a Boolean universe, the Boolean values of $x = y$ and $x \in y$	206
$\ \varphi\ $	the Boolean value of a formula in a Boolean-valued model	207
$V^B$	the Boolean-valued model	209
$\rho(x)$	the rank function in $V^B$	209
$u \Rightarrow v$	$-u + v$	209
$\ x \in y\ , \ x \subset y\ , \ x = y\ $	the Boolean values of atomic formulas in $V^B$	209
$\check{x}$	the canonical name for a set in the ground model	211
$\check{\dot{x}}$	the canonical name for a set in the ground model	212
$\check{G}$	the canonical name for generic ultrafilter	214
$M^B$	the Boolean-valued model inside a transitive model $M$	214
$M^P$	the class of $P$ -names, $M^P = M^{B(P)}$	215
$\Vdash, \Vdash_P$	the forcing relation	215
$p \Vdash \varphi$	$p$ forces $\varphi$	215

$\check{M}$	the canonical name for the ground model	215
$x^G$	the interpretation of a name by a generic ultrafilter	216
$M[G]$	the generic extension of a transitive model $M$	216
$x^G$	the interpretation of a $P$ -name by a generic filter	218
$P \times Q$	the product forcing	229
$G = G_1 \times G_2$	a generic set $G$ is the product of projections $G_1$ and $G_2$ in a product forcing	229
$\prod_{i \in I} P_i$	the product of forcing notions $P_i, i \in I$	230
$s(p)$	the support of a condition in an infinite product forcing, $s(p) = \{i \in I : p(i) \neq 1\}$	230
$G_i, i \in I$	the projections of a generic filter $G$ on the coordinates of the product forcing $\prod_{i \in I} P_i$	230
$P^{\leq \lambda} \times P^{> \lambda}$	the decomposition of Easton product into two parts, one satisfying the $\lambda^+$ -chain condition and the other being $\lambda$ -closed	233
$\text{Col}(\kappa, < \lambda)$	the Lévy collapsing algebra ( $\lambda$ is an inaccessible cardinal)	238
$(P_T, <)$	the forcing associated with a tree $T$	242
$p \leq_n q$	$p \leq q$ and every $n$ th splitting node of $q$ is an $n$ th splitting node of $p$	244
$p \upharpoonright s$	the tree $\{t \in p : t \subset s \text{ or } t \supset s\}$	245
$B_1 \upharpoonright a$	the algebra $\{x \cdot a : x \in B_1\}$ for an $a \in B_2 \supset B_1, a \neq 0$	248
ZFA	set theory with atoms	250
$P^\alpha(S), P^\infty(S)$	the cumulative hierarchy in ZFA	250
$P^\infty(\emptyset)$	the kernel in ZFA	250
$\text{sym}(x)$	the symmetry group of a set in ZFA, the group of permutations $\{\pi \in \mathcal{G} : \pi(x) = x\}$	251
$\text{fix}(E)$	the subgroup of permutations fixed on a set $E$ of a given group	252
$\text{sym}(\dot{x})$	the symmetry group of a name $\dot{x} \in V^B$ , the group of automorphisms of $B, \{\pi \in \mathcal{G} : \pi(\dot{x}) = \dot{x}\}$	253
$HS$	the class of hereditarily symmetric names	253
$x \mapsto \tilde{x}$	an embedding of a permutation model $U$ with the set of atoms $A$ into a symmetric model $N$ of ZF so that $(P_\alpha(A))^U$ and $(P_\alpha(\tilde{A}))^N$ are $\in$ -isomorphic	256
$\diamond'$	a principle equivalent to the Diamond Principle $\diamond$	263
$P * \dot{Q}$	two-step iteration of forcing notions	267
$\Vdash_P \varphi$	$\ \varphi\ _{B(P)} = 1$	267
$G * H$	two-step iteration of generic filters	267
$B * \dot{C}$	the iteration of two complete Boolean algebras	269
$D : B$	the quotient of a complete Boolean algebra $D$ by a filter generated by the generic ultrafilter on a complete subalgebra $B$	269
$P_\alpha$	the iteration of a sequence $\langle \dot{Q}_\beta : \beta < \alpha \rangle$ of names of forcing notions	270
MA, MA $_\kappa$	Martin's Axiom	272
SH	Suslin's Hypothesis	274
$s(p)$	the support of $p, s(p) = \{\beta : \text{not } \Vdash_\beta p(\beta) = 1\}$	280
$f =^* g$	$f$ equals $g$ modulo an ultrafilter $U, \{x \in S : f(x) = g(x)\} \in U$	285
$[f]$	the class of $f$ in $=^*$	285
$f \in^* g, [f] \in^* [g]$	a function $f$ is a member of a function $g$ modulo an ultrafilter $U, \{x \in S : f(x) \in g(x)\} \in U$	285
$\text{Ult}, \text{Ult}_U(V), (\text{Ult}, \in^*)$	the ultraproduct of the universe	285

$j, j_U$	an elementary embedding of $V$ in $Ult$	285
$\text{ext}(f)$	the extension of the equivalence class $[f], \{[g] : g \in^* f\}$	286
$M(X)$	the Mahlo operation for a class $X, M(X) = \{\alpha : X \cap \alpha \text{ is stationary in } \alpha\}$	290
$\mathcal{L}_{\kappa, \omega}$	a language with $\kappa$ variables, and infinitary connectives $\bigvee_{\xi < \alpha}, \bigwedge_{\xi < \alpha}$ , for $\alpha < \kappa$	293
$\mathcal{L}_{\kappa, \kappa}$	a language with $\kappa$ variables, infinitary connectives $\bigvee_{\xi < \alpha}, \bigwedge_{\xi < \alpha}$ , and infinitary quantifiers $\exists_{\xi < \alpha} v_\xi, \forall_{\xi < \alpha} v_\xi$ for $\alpha < \kappa$	293
$c_\xi^\varphi, \xi < \alpha$	Skolem constants	293
$\exists_{\xi < \alpha} v_\xi \varphi(v_\xi, \dots)$	$\exists_{\xi < \alpha} \varphi(c_\xi^\varphi, \dots)_{\xi < \alpha}$ a Skolem sentence for a formula $\varphi$ in an $\mathcal{L}_{\kappa, \kappa}$ language	294
$\Pi_m^n, \Sigma_m^n$	the hierarchy of higher order formulas	295
$h_\varphi(x_1, \dots, x_n)$	a definable Skolem function for a formula $\varphi(u, v_1, \dots, v_n)$	300
$0^\sharp$	zero-sharp, $0^\sharp = \{\varphi : L_{\aleph_\omega} \models \varphi[\aleph_1, \dots, \aleph_n]\}$	312
$h_\varphi(v_1, \dots, v_n)$	the canonical Skolem function for $\varphi(u, v_1, \dots, v_n)$	313
$H^{\mathfrak{A}}(X)$	the Skolem hull of $X$	314
$\Sigma(\mathfrak{A}, I)$	the set of all formulas $\varphi(v_1, \dots, v_n)$ true in $\mathfrak{A}$ for increasing sequences of elements of a set of indiscernibles $I$	314
$Ult = Ult_D(M)$	the ultraproduct of $M$ by an $M$ -ultrafilter $D$	324
$x^\sharp$	$x$ -sharp, $x^\sharp = \{\varphi : (L_{\aleph_\omega}[x], \in, x) \models \varphi[\aleph_1, \dots, \aleph_n]\}$ , for $x \subset \omega$	328
$H^\delta(\alpha \cup p)$	the Skolem hull of $\alpha \cup p$ in $(L_\delta, \in)$	331
$H_n^\rho(Z)$	the $\Sigma_n$ Skolem hull of a set $Z$ in $(L_\rho, \in)$	333
$\{Ult^{(\alpha)}, E^{(\alpha)}, i_{\alpha, \beta} : \alpha, \beta \in Ord\}, Ult_U^{(\alpha)}(V)$	the iterated ultrapowers	342
$U^{(\alpha)}$	the $\kappa^{(\alpha)}$ -complete ultrafilter on $\kappa^{(\alpha)}, U^{(\alpha)} = i_{0, \alpha}(U)$	342
$\kappa^{(\alpha)}$	the measurable cardinal in $Ult^{(\alpha)}, \kappa^{(\alpha)} = i_{0, \alpha}(\kappa)$	344
$U_n$	the product ultrafilters, $U_1 = U, U_{n+1} = \{X \subset \kappa^{n+1} : \{\alpha : \langle \alpha_1, \dots, \alpha_n \rangle : \langle \alpha, \alpha_1, \dots, \alpha_n \rangle \in X\} \in U_n\} \in U\}$	345
$U_E$	the ultrafilter induced by $U_n$ via the order isomorphism between $n =  E $ and $E$	346
$\text{in}_{E, S}(X)$	the inclusion map, $\text{in}_{E, S}(X) = \{t \in \kappa^S : t \upharpoonright E \in X\}$ for $X \subset \kappa^E$	346
$(B_\alpha, \subset)$	the Boolean algebra of sets $Z \subset \kappa^\alpha$ having a finite support, i.e., $Z = \text{in}_{E, \alpha}(X)$ for some $X \subset \kappa^E$ with finite $E \subset \alpha$	347
$0^\dagger$	zero-dagger	353
$\langle M_\gamma : \gamma \leq \lambda \rangle$	the iterated ultrapower of an inner model $M$	356
$o(U)$	the order of a normal measure $U$ (the rank of $U$ in the Mitchell order)	358
$o(\kappa)$	the order of a cardinal $\kappa$ (height of the Mitchell order)	358
$U <_U W$	$\mathcal{U}$ is a closed set of normal measures, $U, W \in \mathcal{U}$ , and $U \in j_W(\mathcal{U})$	358
$o^{\mathcal{U}}(U)$	the order of $U \in \mathcal{U}$ in $<^{\mathcal{U}}$	358
$o^{\mathcal{U}}(\kappa)$	the order of a cardinal $\kappa$ in $<^{\mathcal{U}}$	358
$l(\mathcal{U})$	the length of a set of normal measures $\mathcal{U}$	359
$L\langle A_\alpha : \alpha < \theta \rangle$	the model $L[A]$ where $A = \{(\alpha, X) : X \in A_\alpha\}$	360
$L[\mathcal{U}]$	the model $L\langle U_{\alpha, \beta} : \alpha, \beta \rangle$ where $\mathcal{U} = \{U_{\alpha, \beta} : \alpha, \beta\}$	360
$\hat{x}$	$\{y \in P_\kappa(A) : x \subset y\}$	365
$Ult^-, Ult_U^-(V)$	the version of ultrapower considering only functions on $\lambda^+$ that assume at most $\lambda$ values; $U$ is an ultrafilter on $\lambda^+$ for a cardinal $\lambda$	367
$[f]^-$	the element of the transitive collapse of $Ult^-(V)$ represented by the function $f$	367
$\kappa_x, \lambda_x$	$\kappa_x = x \cap \kappa$ and $\lambda_x =$ the order-type of $x$ , for $x \in P_\kappa(\lambda)$	374



$\alpha_x$	the order type of $x \cap \alpha$	377
VP	Vopěnka's Principle	380
$E = \{E_a : a \in [\lambda]^{<\omega}\}$	the $(\kappa, \lambda)$ -extender derived from an elementary embedding $j$ with critical point $\kappa$	382
$\text{Ult}_E$	the direct limit of the directed system $\{\text{Ult}_{E_a}, i_{a,b} : a \subset b \in [\lambda]^{<\omega}\}$ associated with an extender $E$	382
$j_E : V \rightarrow \text{Ult}_E$	the elementary embedding associated with an extender $E$	382
$\dot{P}_\beta^{(\alpha)}$	the forcing iteration of $\langle \dot{Q}_{\alpha+\xi} : \xi < \beta \rangle$ inside $V^{P_\alpha}$ so that $P_{\alpha+\beta}$ is isomorphic to $P_\alpha * \dot{P}_\beta^{(\alpha)}$	396
$\Delta_s A_s$	$\{\alpha < \kappa : \alpha \in \bigcap \{A_s : \max(s) < \alpha\}\}$	402
$A \setminus s$	$A - (\max(s) + 1)$ for $A \subset \kappa$ and $s \in [\kappa]^{<\omega}$	403
$\text{sat}(I)$	$\text{sat}(P(\kappa)/I)$ where $I$ is an ideal on $\kappa$	409
$f_*(I)$	the ideal $\{X \subset \kappa : f_{-1}(X) \in I\}$ where $I$ is an ideal and $f$ is an ideal on $\kappa$	410
$f_*(\mu)$	the measure $\nu$ defined by $\nu(X) = \mu(f_{-1}(X))$ where $f : \kappa \rightarrow \kappa$ and $\mu$ is a (real-valued) measure on $\kappa$	410
$g < h$	$\text{dom}(g) \subset \text{dom}(h)$ and $g(\alpha) \leq h(\alpha)$ for $\alpha \in \text{dom}(g)$ where $g$ and $h$ are functions into $\kappa$ defined on a set of positive measure	411
$\text{Ult}_G(M)$	the generic ultrapower where $G$ is a generic ultrafilter on $P(\kappa)/I$	421
$j_G$	the canonical embedding from $M$ into $\text{Ult}_G(M)$	421
$W_1 \leq W_2$	the $I$ -partition $W_1$ is a refinement of the $I$ -partition $W_2$	424
$W_F$	the $I$ -partition $\{\text{dom}(f) : f \in F\}$ associated with a functional $F$	424
$\mathcal{G}_I$	the infinite game on sets of positive $I$ -measure played by the players Empty and Nonempty	426
$\diamond(E)$	the Diamond Principle restricted to a stationary set $E$	442
$\diamond_\kappa$	the Diamond Principle $\diamond(\kappa)$	442
$\square_\kappa$	Jensen's Square Principle	443
$P_S$	the forcing shooting a closed unbounded set (conditions are bounded closed subsets of a stationary set $S$ ; $p$ is stronger than $q$ if $q = p \cap \alpha$ for some $\alpha$ )	445
$I^+$	$\{S \subset \kappa : S \notin I\}$	450
$I \upharpoonright S$	$\{X \subset \kappa : X \cap S \in I\}$ , the ideal concentrating on a set $S$	450
Reg	$\{\alpha < \kappa : \alpha \text{ is a regular cardinal}\}$	452
$\ \varphi\ $	the (rank) norm of a function $\varphi : \omega_1 \rightarrow \omega_1$	458
$f =_I g, f \leq_I g, f <_I g$	the relations between functions modulo an ideal on an infinite set	460
$f =_F g, f \leq_F g, f <_F g$	the relations between functions modulo the dual ideal to a filter $F$	460
$\ f\ $	Galvin-Hajnal norm of an ordinal function $f$	460
$f_\eta, \eta < \kappa^+$	the canonical ordinal functions	461
$\text{cof } D, \text{cof } \prod A/D$	the cofinality of the ultraproduct $\prod A/D$ in the ordering $<_D$	466
$\text{pcf } A$	the set of all cofinalities of ultraproducts $\prod A/U$	466
$M_\alpha^a, \alpha < \omega_k$	an elementary chain of submodels of some $(H_\theta, \in, <)$ where $<$ is a well-ordering of $H_\theta$ with $M_\alpha^a \supset a \cup \omega_k$ for a countable set $a \subset \omega_k$	468
$\chi_\alpha^a$	the characteristic function of $M_\alpha^a$ for a countable set $a \subset \omega_k$ and $\alpha < \omega_k, \chi_\alpha^a(n) = \sup(M_\alpha^a \cap \omega_n)$	468
$M^a$	$M^a = \bigcup_{\alpha < \omega_k} M_\alpha^a$ for a countable set $a \subset \omega_k$	468
$\chi^a$	the characteristic function of $M^a$ for a countable set $a \subset \omega_k$	468

$B_\lambda \subset A, \lambda \in \text{pcf } A$	the generators of pcf $A$	470
$J_\lambda$	the ideal generated by the sets $B_\nu, \nu < \lambda$	470
$J_\kappa[B_\kappa]$	the ideal generated by $J_\kappa \cup \{B_\kappa\}$	471
$\overline{B}_\lambda, \lambda \in A$	the transitive generators of pcf $A$	474
$\Sigma_n^1, \Pi_n^1, \Delta_n^1$	the lightface hierarchy of projective sets	479
$\Sigma_n^1(a), \Pi_n^1(a), \Delta_n^1(a)$	the relativization of the hierarchy of projective sets	479
$\Sigma_n^0, \Pi_n^0$	the lightface Borel hierarchy (hierarchy of arithmetical sets)	480
$u_m, m \in \mathbf{N}$ (or $z_m, m \in \mathbf{N}$ )	the canonical homeomorphism between $\mathcal{N}$ and $\mathcal{N}^\omega$ ; $u_m(n) = u(\Gamma(m, n))$	482
$Seq_r$	the set of $r$ -tuples of sequences of natural numbers of the same length	483
$T(x)$	the tree $\{(s_1, \dots, s_r) \in Seq_r : (x \upharpoonright n, s_1, \dots, s_r) \in T \text{ where } n = \text{length } s_i\}$	483
$T/s$	the tree $\{t : s \hat{\ } t \in T\}$	484
$\ T\ $	the height of a well-founded tree $T$	484
$\rho_T(t)$	the rank of an element $t$ of a well-founded tree $T$	484
$[T]$	$\{f \in X^\omega : \forall n f \upharpoonright n \in T\}$	484
$Seq(K)$	the set of all finite sequences in $K$	485
$p[T]$	$\{x \in \mathcal{N} : T(x) \text{ is ill-founded}\}$	485
$E_x$	the relation $\{(m, n) : x(\Gamma(m, n)) = 0\}$ coded by $x \in \mathcal{N}$	485
WF	$\{x \in \mathcal{N} : x \text{ codes a well-founded relation}\}$	485
WO	$\{x \in \mathcal{N} : x \text{ codes a well-ordering on } \mathbf{N}\}$	485
$\preceq_\varphi$	the prewellordering induced by a norm $\varphi$ ; $a \preceq_\varphi b \leftrightarrow \varphi(a) \leq \varphi(b)$	496
$\delta_2^1$	$\sup\{\alpha : \alpha \text{ is the length of a } \Sigma_2^1 \text{ prewellordering}\}$	502
$I_1, I_2, \dots, I_k, \dots$	a recursive enumeration of open intervals with rational endpoints	504
$u(c), v_i(c)$	the elements of $\mathcal{N}$ defined, for $c \in \mathcal{N}$ and $i \in \mathbf{N}$ , by $u(c)(n) = c(n+1), v_i(c)(n) = c(\Gamma(i, n) + 1)$	504
$\Sigma_\alpha, \Pi_\alpha$	the set of $\Sigma_\alpha^0$ -codes and the set of $\Pi_\alpha^0$ -codes, respectively, $0 < \alpha < \omega_1$	504
BC	the set of all Borel codes $\bigcup_{\alpha < \omega_1} \Sigma_\alpha = \bigcup_{\alpha < \omega_1} \Pi_\alpha$	504
$A_c$	the Borel set coded by a $c \in \text{BC}$	504
$I_m, I_c$	the ideals $\{B \in \mathcal{B} : \mu(B) = 0\}$ and $\{B \in \mathcal{B} : B \text{ is meager}\}$ , respectively	511
$\mathcal{B}_m, \mathcal{B}_c$	the quotient algebras $\mathcal{B}/I_m$ and $\mathcal{B}/I_c$ , respectively	511
$B^*$	the Borel set $A_c$ if $B = A_c^M$ for some $c \in M$	511
$R(M), C(M)$	the sets of all random and all Cohen reals over $M$ , respectively	514
$\text{Col}(\aleph_0, \lambda)$	the collapsing algebra	516
$A \setminus s$	$A - (\max(s) + 1)$ for $A \subset \omega$ and $s \in [\omega]^{<\omega}$	524
$[s, A]$	$\{X \in [\omega]^\omega : s \subset X \text{ and } X \setminus s \subset A\}$	524
$\text{add}(\text{LM}), \text{cov}(\text{LM}), \text{unif}(\text{LM}), \text{cof}(\text{LM})$	the cardinal invariants of Lebesgue measure	532
$\text{add}(\text{BP}), \text{cov}(\text{BP}), \text{unif}(\text{BP}), \text{cof}(\text{BP})$	the cardinal invariants of the Baire property	532
$\mathfrak{d}, \mathfrak{b}$	the dominating number and the bounding number, respectively	533
$\mathfrak{t}$	the least cardinality of a tower	540
$\mathfrak{u}$	the least cardinality of a family of subsets of $\omega$ that generates an ultrafilter	540
$\text{rud}(M)$	the rudimentary closure of $M \cup \{M\}$	548
$J_\alpha, \alpha \in \text{Ord}$	the Jensen hierarchy of constructible sets	548

$\rho_\alpha^n$	the $\Sigma_n$ -projectum of $\alpha$ , i.e., the least $\rho \leq \alpha$ such that there is a $\Sigma_n(J_\alpha)$ function such that $f^{\omega} J_\rho = J_\alpha$	549
$p \upharpoonright s$	the tree $\{t \in p : t \subset s \text{ or } t \supset s\}$ for a tree $p$ and $s \in p$	557
$\mathcal{F}(T)$	the fusion $\bigcap_{n=0}^\infty \bigcup_{s \in \{0,1\}^n} T(s)$ for a fusionable collection of perfect trees $T = \{T(s) : s \in \text{Seq}(\{0,1\})\}$	558
$T'$	the tree $\{t \in T : t \text{ has } \aleph_2 \text{ extensions in } T\}$ where $T \subset \omega_2^{<\omega}$ is a tree	561
$h_T(t)$	the least $\alpha$ such that $t \notin T_{\alpha+1}$ where $T_\alpha$ is defined by induction: $T_0 = T$ , $T_{\alpha+1} = T'_\alpha$ , and $T_\alpha = \bigcap_{\beta < \alpha} T_\beta$ if $\alpha$ is limit	561
$s_p$	the stem of a Laver tree $p$	565
$S^p(t)$	the set $\{a \in \omega : t \frown a \in p\}$ where $p$ is a Laver tree and $t \in p$	565
$s_i^p, i = 0, 1, \dots$	a canonical enumeration of nodes in a Laver tree $p$	565
$q \leq_n p$	$q \leq p$ and $s_i^q \in q$ for all $i = 0, \dots, n$ where $p, q$ are Laver trees	565
$U + V$	the ultrafilter $\{X \subset N : \{m \in N : X - m \in V\} \in U\}$ where $X - m = \{n : m + n \in X\}$ and $U, V$ are ultrafilters on $N$	573
$\beta N$	the Stone-Ćech compactification of $N$	573
$A^*$	the clopen set $\{V \in \beta N : A \in V\}$ in $\beta N$ for $A \subset N$	574
OCA	the Open Coloring Axiom	576
$I \times J$	the ideal of sets $X \subset S \times T$ such that $\{x \in S : \{y \in T : (x, y) \in X\} \notin J\} \in I$ where $I$ and $J$ are ideals on $S$ and $T$ , respectively	580
$C_\kappa$	the complete Boolean algebra of the forcing for adding $\kappa$ Cohen reals	588
$\bar{B}$	the completion of a Boolean algebra $B$	588
$A \leq_{\text{reg}} B$	$A$ is a regular subalgebra of a Boolean algebra $B$	588
$\text{pr}_A^B(b), \text{pr}_A(b)$	the projections of $b$ to a subalgebra $A$	589
$\langle X \rangle$	the subalgebra generated by a set $X$	589
$A(b_1, \dots, b_n)$	the subalgebra generated by the set $A \cup \{b_1, \dots, b_n\}$ where $A$ is a subalgebra	589
$P_S, C_S$	$C_S = B(P_S)$ and $P_S$ is the forcing consisting of finite 0–1 functions with domain $\subset S$	589
$\text{Fr}_G$	the free Boolean algebra with a set $G$ of free generators	590
$\limsup_n a_n$	$\prod_{n=0}^\infty \sum_{k \geq n} a_n$ (a Boolean operation)	598
$\liminf_n a_n$	$\sum_{n=0}^\infty \prod_{k \geq n} a_n$ (a Boolean operation)	598
$\lim_n a_n$	the common value of $\limsup_n a_n$ and $\liminf_n a_n$ provided that they are equal	598
$M[G]$	$\{\dot{x}^G : \dot{x} \in M\}$ where $M \prec H_\lambda$ and $G$ is $V$ -generic	605
PFA	the Proper Forcing Axiom	607
$T \upharpoonright C$	the tree $\{t \in T : o(t) \in C\}$ where $T$ is an $\omega_1$ -tree and $C \subset \omega_1$ is a closed unbounded set	612
$\text{PFA}^+$	if $\mathcal{D} = \{D_\alpha : \alpha < \omega_1\}$ are dense subsets of a proper forcing $P$ and if $\Vdash \dot{S} \subset \omega_1$ is stationary, then there exists a $\mathcal{D}$ -generic filter $G$ such that $\dot{S}^G$ is stationary	613
$\text{PFA}^-$	if $P$ is proper such that $ P  \leq \aleph_1$ and if $\mathcal{D} = \{D_\alpha : \alpha < \omega_1\}$ are dense then there exists a $\mathcal{D}$ -generic filter	614
$G_A$	the game of players I and II in which the players choose the consecutive members of a sequence of natural numbers $\langle a_0, b_0, a_1, b_1, \dots \rangle$ ; I wins if the sequence is in the set $A \subset \omega^\omega$ and otherwise II wins	627
AD	the Axiom of Determinacy	627

$\sigma * b$	a play played by player I by a strategy $\sigma$ in the game $G_A$	627
$a * \tau$	a play played by player II by a strategy $\tau$ in the game $G_A$	627
PD	the Projective Determinacy	628
$AD^{L(\mathbf{R})}$	the Axiom of Determinacy in $L(\mathbf{R})$	628
$\text{cone}(x_0)$	the cone $\{x \in \mathcal{N} : x_0 \in L[x]\}$	633
$\delta_n^1$	$\sup\{\xi : \xi \text{ is the length of a } \Delta_n^1 \text{ prewellordering of } \mathcal{N}\}$ (the projective ordinal)	636
$\Theta$	$\sup\{\xi : \xi \text{ is the length of a prewellordering of } \mathcal{N}\}$	636
$G_A^{(a_0, b_0, \dots, a_n, b_n)}$	the game in which player I plays $\langle a_{n+1}, a_{n+2} \dots \rangle$ , player II plays $\langle b_{n+1}, b_{n+2} \dots \rangle$ , and in which II wins when $\langle a_0, b_0, a_1, b_1, \dots \rangle \in A$	637
$G_A^{a_0}$	the game in which II makes a first move $b_0$ , then I plays $a_1$ , etc., and II wins if $\langle a_0, b_0, a_1, b_1, \dots \rangle \in \mathcal{N} - A$	637
$\preceq$	the linear ordering of $Seq$ that extends the partial ordering $\supset$	638
$T_s$	$\{t \in Seq : (u, t) \in T \text{ for some } u \subset s\}$ where $T \subset Seq_2$ is a tree and $s \in Seq$	638
$K_s$	the set $\{t_0, \dots, t_{n-1}\} \cap T_s$ where $ s  = 2n$ , $\{t_n : n \in \omega\}$ is an enumeration of $Seq$ and $T \subset Seq_2$ is a tree	638
$k_s$	the size of the finite set $K_s$	638
$T_s$	the set $\{t \in Seq : (s, t) \in T \text{ for some } s \in Seq\}$ and a tree $T$ on $\omega^r \times K$	642
$\mu_s, s \in Seq$	the measures on $T_s$ 's ensuring that the tree $T$ on $\omega \times K$ is homogeneous	642
$\mu_{s,t}$	the natural projection map from $T_t$ to $T_s$ for $s \subset t$ in $Seq$	642
$Q, Q_{<\kappa}$	the stationary tower forcing	653
$f =_G g, f \in_G g$	the predicates in the generic ultrapower by the stationary tower forcing	653
$K$	the core model up to a measurable cardinal	660
$\text{rud}_A(M)$	the closure of $M \cup \{M\}$ under functions rudimentary in $A$	660
$J_\alpha^A, \alpha \in Ord$	the relativized Jensen hierarchy of sets	660
$\mathcal{C}_\lambda$	the closed unbounded filter on $\lambda$	661
$M < M'$	the well-ordering of mice	662
$K^m$	the core model up to $o(\kappa) = \kappa^{++}$	664
$K^{\text{strong}}$	the core model up to a strong cardinal	666
$\rho_M^1$	the $\Sigma_1$ -projectum of $M$	667
$MS = \bigcup_{n=0}^\infty MS_n$	the class of all measure sequences	676
$R_U$	the Radin forcing for a measure sequence $U$	677
MM	Martin's Maximum	681
SPFA	Semiproper Forcing Axiom	681
RCS	revised countable support iteration	682
$X^\perp$	$X^\perp = \{M \in [H_\lambda]^\omega : M \prec H_\lambda \text{ and } N \notin X \text{ for every countable } N \text{ that satisfies } M \prec N \prec H_\lambda \text{ and } N \cap \omega_1 = M \cap \omega_1\}$	684
RP, RP( $\lambda$ )	the Reflection Principle	688
SRP, SRP( $\lambda$ )	the Strong Reflection Principle	688
$IA$	the set of all internally approachable models	699
$\square_{\kappa, \nu}, \square_{\kappa, <\nu}$	weaker square principles	702
$\square_{\kappa, \kappa}, \square_{\kappa}^*$	the Weak Square	702
$F_n^1$	the $\Pi_n^1$ filter	703
$AD_{\mathbf{R}}$	the determinacy of games where moves are real numbers	705

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