

# Bibliographic guide to the foundations of quantum mechanics and quantum information

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“[T]here’s much more difference (...) between a human being who knows quantum mechanics and one that doesn’t than between one that doesn’t and the other great apes.”

M. Gell-Mann

at the annual meeting of the American Association for the Advancement of Science, Chicago 11 Feb. 1992.

Reported in [**Siegfried 00**], pp. 177-178.

“The Copenhagen interpretation *is* quantum mechanics.”

R. Peierls.

Reported in [**Khalfin 90**], p. 477.

“Quantum theory needs no ‘interpretation’.”

C. A. Fuchs and A. Peres.

Title of [**Fuchs-Peres 00 a**].

“Unperformed experiments have no results.”

A. Peres.

Title of [**Peres 78 a**].

## Introduction

This is a collection of references (papers, books, preprints, book reviews, Ph. D. thesis, patents, web sites, etc.), sorted alphabetically and (some of them) classified by subject, on foundations of quantum mechanics and quantum information. Specifically, it covers hidden variables (“no-go” theorems, experiments), “interpretations” of quantum mechanics, entanglement, quantum effects (quantum Zeno effect, quantum erasure, “interaction-free” measurements, quantum “non-demolition” measurements), quantum information (cryptography, cloning, dense coding, teleportation), and quantum computation. For a more detailed account of the subjects covered, please see the table of contents in the next pages.

Most of this work was developed for personal use, and is therefore biased towards my own preferences, tastes and phobias. This means that the selection is incomplete, although some effort has been made to cover some gaps. Some closely related subjects such as quantum chaos, quantum structures, geometrical phases, relativistic quantum mechanics, or Bose-Einstein condensates have been deliberately excluded.

Please note that this guide has been directly written in LaTeX (REVTeX4) and therefore a corresponding BibTeX file does not exist, so do not ask for it.

Please e-mail corrections to [adan@us.es](mailto:adan@us.es) (under subject: Error). Indicate the references as, for instance, [**von Neumann 31**], not by its number (since this number may have been changed in a later version). Suggestions for additional (essential) references which ought to be included are welcome (please e-mail to [adan@us.es](mailto:adan@us.es) under subject: Suggestion).

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## I. HIDDEN VARIABLES

### A. Von Neumann's impossibility proof

[von Neumann 31], [von Neumann 32] (Sec. IV. 2), [Hermann 35], [Albertson 61], [Komar 62], [Bell 66, 71], [Capasso-Fortunato-Selleri 70], [Wigner 70, 71], [Clauser 71 a, b], [Gudder 80] (includes an example in two dimensions showing that the expected value cannot be additive), [Selleri 90] (Chap. 2), [Peres 90 a] (includes an example in two dimensions showing that the expected value cannot be additive), [Ballentine 90 a] (in pp. 130-131 includes an example in four dimensions showing that the expected value cannot be additive), [Zimba-Clifton 98], [Busch 99 b] (resurrection of the theorem), [Giuntini-Laudisa 01].

### B. Einstein-Podolsky-Rosen's argument of incompleteness of QM

#### 1. General

[Anonymous 35], [Einstein-Podolsky-Rosen 35], [Bohr 35 a, b] (see IB 2), [Schrödinger 35 a, b, 36], [Furry 36 a, b], [Einstein 36, 45] (later Einstein's arguments of incompleteness of QM), [Epstein 45], [Bohm 51] (Secs. 22. 16-19. Reprinted in [Wheeler-Zurek 83], pp. 356-368; simplified version of the EPR's example with two spin- $\frac{1}{2}$  atoms in the singlet state), [Bohm-Aharonov 57] (proposal of an experimental test with photons correlated in polarization. Comments:), [Peres-Singer 60], [Bohm-Aharonov 60]; [Sharp 61], [Putnam 61], [Breitenberger 65], [Jammer 66] (Appendix B; source of additional bibliography), [Hooker 70] (the quantum approach does not "solve" the paradox), [Hooker 71], [Hooker 72 b] (Einstein vs. Bohr), [Krips 71], [Ballentine 72] (on Einstein's position toward QM), [Moldauer 74], [Zweifel 74] (Wigner's theory of measurement solves the paradox), [Jammer 74] (Chap. 6, complete account of the historical development), [McGrath 78] (a logic formulation), [Cantrell-Scully 78] (EPR according QM), [Pais 79] (Einstein and QM), [Jammer 80] (includes photographs of Einstein, Podolsky, and Rosen from 1935, and the New York Times article on EPR, [Anonymous 35]), [Koç 80, 82], [Caser 80], [Mückenheim 82], [Costa de Beauregard 83], [Mittelstaedt-Stachow 83] (a logical and relativistic formulation), [Vujicic-Herbut 84], [Howard 85] (Einstein on EPR and other later arguments), [Fine 86] (Einstein and realism), [Griffiths 87] (EPR experiment in the consistent histories interpretation), [Fine 89] (Sec. 1, some historical remarks), [Pykacz-Santos 90] (a logical formulation with axioms derived from experiments), [Deltete-Guy 90] (Einstein and QM), (Einstein and the statistical interpretation of QM:) [Guy-Deltete 90], [Stapp 91], [Fine

91]; [Deltete-Guy 91] (Einstein on EPR), [Hájek-Bub 92] (EPR's argument is "better" than later arguments by Einstein, contrary to Fine's opinion), [Combourieu 92] (Popper on EPR, including a letter by Einstein from 1935 with containing a brief presentation of EPR's argument), [Bohm-Hiley 93] (Sec. 7. 7, analysis of the EPR experiment according to the "causal" interpretation), [Schatten 93] (hidden-variable model for the EPR experiment), [Hong-yi-Klauder 94] (common eigenvectors of relative position and total momentum of a two-particle system, see also [Hong-yi-Xiong 95]), [De la Torre 94 a] (EPR-like argument with two components of position and momentum of a single particle), [Dieks 94] (Sec. VII, analysis of the EPR experiment according to the "modal" interpretation), [Eberhard-Rosselet 95] (Bell's theorem based on a generalization of EPR criterion for elements of reality which includes values predicted with almost certainty), [Paty 95] (on Einstein's objections to QM), [Jack 95] (easy-reading introduction to the EPR and Bell arguments, with Sherlock Holmes).

#### 2. Bohr's reply to EPR

[Bohr 35 a, b], [Hooker 72 b] (Einstein vs. Bohr), [Koç 81] (critical analysis of Bohr's reply to EPR), [Beller-Fine 94] (Bohr's reply to EPR), [Ben Menahem 97] (EPR as a debate between two possible interpretations of the uncertainty principle: The *weak* one—it is not possible to measure or prepare states with well defined values of conjugate observables—, and the *strong* one—such states do not even exist—. In my opinion, this paper is extremely useful to fully understand Bohr's reply to EPR), [Dickson 01] (Bohr's thought experiment is a reasonable realization of EPR's argument), [Halvorson-Clifton 01] (the claims that the point in Bohr's reply is a radical positivist are unfounded).

### C. Gleason theorem

[Gleason 57], [Piron 72], simplified unpublished proof by Gudder mentioned in [Jammer 74] (p. 297), [Krips 74, 77], [Eilers-Horst 75] (for non-separable Hilbert spaces), [Piron 76] (Sec. 4. 2), [Drisch 79] (for non-separable Hilbert spaces and without the condition of positivity), [Cooke-Keane-Moran 84, 85], [Redhead 87] (Sec. 1. 5), [Maeda 89], [van Fraassen 91 a] (Sec. 6. 5), [Hellman 93], [Peres 93 a] (Sec. 7. 2), [Pitowsky 98 a], [Busch 99 b], [Wallach 02] (an "unentangled" Gleason's theorem), [Hrushovski-Pitowsky 03] (constructive proof of Gleason's theorem, based on a generic, finite, effectively generated set of rays, on which every quantum state can be approximated), [Busch 03 a] (the idea of a state as an expectation value assignment is extended to that of a generalized probabilistic measure on the set of all elements of a POVM. All

such generalized probability measures are found to be determined by a density operator. Therefore, this result is a simplified proof and, at the same time, a more comprehensive variant of Gleason’s theorem), [Caves-Fuchs-Manne-Renes 04] (Gleason-type derivations of the quantum probability rule for POVMs).

#### D. Other proofs of impossibility of hidden variables

[Jauch-Piron 63], [Misra 67], [Gudder 68].

#### E. Bell-Kochen-Specker theorem

##### 1. The BKS theorem

[Specker 60], [Kochen-Specker 65 a, 65 b, 67], [Kamber 65], [Zierler-Schlessinger 65], [Bell 66], [Belinfante 73] (Part I, Chap. 3), [Jammer 74] (pp. 322-329), [Lenard 74], [Jost 76] (with 109 rays), [Galindo 76], [Hultgren-Shimony 77] (Sec. VII), [Hockney 78] (BKS and the “logic” interpretation of QM proposed by Bub; see [Bub 73 a, b, 74]), [Alda 80] (with 90 rays), [Nelson 85] (pp. 115-117), [de Obaldia-Shimony-Wittel 88] (Belinfante’s proof requires 138 rays), [Peres-Ron 88] (with 109 rays), unpublished proof using 31 rays by Conway and Kochen (see [Peres 93 a], p. 114, and [Cabello 96] Sec. 2. 4. d.), [Peres 91 a] (proofs with 33 rays in dimension 3 and 24 rays in dimension 4), [Peres 92 c, 93 b, 96 b], [Chang-Pal 92], [Mermin 93 a, b], [Peres 93 a] (Sec. 7. 3), [Cabello 94, 96, 97 b], [Kernaghan 94] (proof with 20 rays in dimension 4), [Kernaghan-Peres 95] (proof with 36 rays in dimension 8), [Pagonis-Clifton 95] [why Bohm’s theory eludes BKS theorem; see also [Dewdney 92, 93], and [Hardy 96] (the result of a measurement in Bohmian mechanics depends not only on the context of other simultaneous measurements but also on how the measurement is performed)], [Baccigaluppi 95] (BKS theorem in the modal interpretation), [Bell 96], [Cabello-García Alcaine 96 a] (BKS proofs in dimension  $n \geq 3$ ), [Cabello-Estebarez-García Alcaine 96 a] (proof with 18 rays in dimension 4), [Cabello-Estebarez-García Alcaine 96 b], [Gill-Keane 96], [Svozil-Tkadlec 96], [DiVincenzo-Peres 96], [García Alcaine 97], [Calude-Hertling-Svozil 97] (two geometric proofs), [Cabello-García Alcaine 98] (proposed *gedanken* experimental test on the existence of non-contextual hidden variables), [Isham-Butterfield 98, 99], [Hamilton-Isham-Butterfield 99], [Butterfield-Isham 01] (an attempt to construct a realistic contextual interpretation of QM), [Svozil 98 b] (book), [Massad 98] (the Penrose dodecahedron), [Aravind-Lee Elkin 98] (the 60 and 300 rays corresponding respectively to antipodal pairs of vertices of the 600-cell 120-cell—the two most complex of the four-dimensional regular polytopes— can both be used

to prove BKS theorem in four dimensions. These sets have critical non-colourable subsets with 44 and 89 rays), [Clifton 99, 00 a] (KS arguments for position and momentum components), [Bassi-Ghirardi 99 a, 00 a, b] (decoherent histories description of reality cannot be considered satisfactory), [Griffiths 00 a, b] (there is no conflict between consistent histories and Bell and KS theorems), [Michler-Weinfurter-Żukowski 00] (experiments), [Simon-Żukowski-Weinfurter-Zeilinger 00] (proposal for a *gedanken* KS experiment), [Aravind 00] (Reye’s configuration and the KS theorem), [Aravind 01 a] (the magic tesseracts and Bell’s theorem), [Conway-Kochen 02], [Myrvold 02 a] (proof for position and momentum), [Cabello 02 k] (KS theorem for a single qubit), [Pavičić-Merlet-McKay-Megill 04] (exhaustive construction of all proofs of the KS theorem; the one in [Cabello-Estebarez-García Alcaine 96 a] is the smallest).

##### 2. From the BKS theorem to the BKS with locality theorem

[Gudder 68], [Maczyński 71 a, b], [van Fraassen 73, 79], [Fine 74], [Bub 76], [Demopoulos 80], [Bub 79], [Humphreys 80], [van Fraassen 91 a] (pp. 361-362).

##### 3. The BKS with locality theorem

Unpublished work by Kochen from the early 70’s, [Heywood-Redhead 83], [Stairs 83 b], [Krips 87] (Chap. 9), [Redhead 87] (Chap. 6), [Brown-Svetlichny 90], [Elby 90 b, 93 b], [Elby-Jones 92], [Clifton 93], (the Penrose dodecahedron and its sons:), [Penrose 93, 94 a, b, 00], [Zimba-Penrose 93], [Penrose 94 c] (Chap. 5), [Massad 98], [Massad-Aravind 99]; [Aravind 99] (any proof of the BKS can be converted into a proof of the BKS with locality theorem).

##### 4. Probabilistic versions of the BKS theorem

[Stairs 83 b] (pp. 588-589), [Home-Sengupta 84] (statistical inequalities), [Clifton 94] (see also the comments), [Cabello-García Alcaine 95 b] (probabilistic versions of the BKS theorem and proposed experiments).

##### 5. The BKS theorem and the existence of dense “KS-colourable” subsets of projectors

[Godsil-Zaks 88] (rational unit vectors in  $d = 3$  do not admit a “regular colouring”), [Meyer 99 b] (rational unit vectors are a dense KS-colourable subset in dimension 3), [Kent 99 b] (dense colourable subsets of projectors exist in any arbitrary finite dimensional real

or complex Hilbert space), [Clifton-Kent 00] (dense colourable subsets of projectors exist with the remarkable property that every projector belongs to only one resolution of the identity), [Cabello 99 d], [Havlicek-Krenn-Summhammer-Svozil 01], [Mermin 99 b], [Appleby 00, 01, 02, 03 b], [Mushtari 01] (rational unit vectors do not admit a “regular colouring” in  $d = 3$  and  $d \geq 6$ , but do admit a “regular colouring” in  $d = 4$  —an explicit example is presented— and  $d = 5$  —result announced by P. Ovchinnikov—), [Boyle-Schafir 01 a], [Cabello 02 c] (dense colourable subsets cannot simulate QM because most of the many possible colourings of these sets must be statistically irrelevant in order to reproduce some of the statistical predictions of QM, and then, the remaining statistically relevant colourings cannot reproduce some different predictions of QM), [Breuer 02 a, b] (KS theorem for unsharp spin-one observables), [Peres 03 d], [Barrett-Kent 04].

### 6. The BKS theorem in real experiments

[Simon-Żukowski-Weinfurter-Zeilinger 00] (proposal), [Simon-Brukner-Zeilinger 01], [Larsson 02 a] (a KS inequality), [Huang-Li-Zhang-(+2) 03] (realization of all-or-nothing-type KS experiment with single photons).

## F. Bell’s inequalities

### 1. First works

[Bell 64, 71], [Clauser-Horne-Shimony-Holt 69], [Clauser-Horne 74], [Bell 87 b] (Chaps. 7, 10, 13, 16), [d’Espagnat 93] (comparison between the assumptions in [Bell 64] and in [Clauser-Horne-Shimony-Holt 69]).

### 2. Bell’s inequalities for two spin- $s$ particles

[Mermin 80] (the singlet state of two spin- $s$  particles violates a particular Bell’s inequality for a range of settings that vanishes as  $\frac{1}{s}$  when  $s \rightarrow \infty$ ) [Mermin-Schwarz 82] (the  $\frac{1}{s}$  vanishing might be peculiar to the particular inequality used in [Mermin 80]), [Garg-Mermin 82, 83, 84] (for some Bell’s inequalities the range of settings does not diminish as  $s$  becomes arbitrarily large), [Ögren 83] (the range of settings for which quantum mechanics violates the original Bell’s inequality is the same magnitude, at least for small  $s$ ), [Mermin 86 a], [Braunstein-Caves 88], [Sanz-Sánchez Gómez 90], [Sanz 90] (Chap. 4), [Ardehali 91] (the range of settings vanishes as  $\frac{1}{s^2}$ ), [Gisin 91 a] (Bell’s inequality holds for all non-product states), [Peres 92 d], [Gisin-Peres 92] (for two spin- $s$  particles in the singlet state the violation of the CHSH inequality is *con-*

*stant* for any  $s$ ; large  $s$  is no guarantee of classical behavior) [Geng 92] (for two different spins), [Wódkiewicz 92], [Peres 93 a] (Sec. 6. 6), [Wu-Zong-Pang-Wang 01 a] (two spin-1 particles), [Kaszlikowski-Gnaciński-Żukowski-(+2) 00] (violations of local realism by two entangled  $N$ -dimensional systems are stronger than for two qubits), [Chen-Kaszlikowski-Kwek-(+2) 01] (entangled three-state systems violate local realism more strongly than qubits: An analytical proof), [Collins-Gisin-Linden-(+2) 01] (for arbitrarily high dimensional systems), [Collins-Popescu 01] (violations of local realism by two entangled quNits), [Kaszlikowski-Kwek-Chen-(+2) 02] (Clauser-Horne inequality for three-level systems), [Acín-Durt-Gisin-Latorre 02] (the state  $\frac{1}{\sqrt{2+\gamma^2}}(|00\rangle + \gamma|11\rangle + |22\rangle)$ , with  $\gamma = (\sqrt{11} - \sqrt{3})/2 \approx 0.7923$ , can violate the Bell inequality in [Collins-Gisin-Linden-(+2) 01] more than the state with  $\gamma = 1$ ), [Thew-Acín-Zbinden-Gisin 04] (Bell-type test of energy-time entangled qutrits).

### 3. Bell’s inequalities for two particles and more than two observables per particle

[Braunstein-Caves 88, 89, 90] (chained Bell’s inequalities, with more than two alternative observables on each particle), [Gisin 99], [Collins-Gisin 03] (for three possible two-outcome measurements per qubit, there is only one inequality which is inequivalent to the CHSH inequality; there are states which violate it but do not violate the CHSH inequality).

### 4. Bell’s inequalities for $n$ particles

[Greenberger-Horne-Shimony-Zeilinger 90] (Sec. V), [Mermin 90 c], [Roy-Singh 91], [Clifton-Redhead-Butterfield 91 a] (p. 175), [Hardy 91 a] (Secs. 2 and 3), [Braunstein-Mann-Revzen 92], [Ardehali 92], [Klyshko 93], [Belinsky-Klyshko 93 a, b], [Braunstein-Mann 93], [Hnilo 93, 94], [Belinsky 94 a], [Greenberger 95], [Żukowski-Kaszlikowski 97] (critical visibility for  $n$ -particle GHZ correlations to violate local realism), [Pitowsky-Svozil 00] (Bell’s inequalities for the GHZ case with two and three local observables), [Werner-Wolf 01 b], [Żukowski-Brukner 01], [Scarani-Gisin 01 b] (pure entangled states may exist which do not violate Mermin-Klyshko inequality), [Chen-Kaszlikowski-Kwek-Oh 02] (Clauser-Horne-Bell inequality for three three-dimensional systems), [Brukner-Laskowski-Żukowski 03] (multiparticle Bell’s inequalities involving many measurement settings: the inequalities reveal violations of local realism for some states for which the two settings-per-local-observer inequalities fail in this task), [Laskowski-Paterek-Żukowski-Brukner 04].

### 5. Which states violate Bell's inequalities?

(Any pure entangled state does violate Bell-CHSH inequalities:) [Capasso-Fortunato-Selleri 73], [Gisin 91 a] (some corrections in [Barnett-Phoenix 92]), [Werner 89] (one might naively think that as in the case of pure states, the only mixed states which do not violate Bell's inequalities are the mixtures of product states, i.e. separable states. Werner shows that this conjecture is false), (maximum violations for pure states:) [Popescu-Rohrlich 92], (maximally entangled states violate maximally Bell's inequalities:) [Kar 95], [Cereceda 96 b]. For mixed states: [Braunstein-Mann-Revzen 92] (maximum violation for mixed states), [Mann-Nakamura-Revzen 92], [Beltrametti-Maczyński 93], [Horodecki-Horodecki-Horodecki 95] (necessary and sufficient condition for a mixed state to violate the CHSH inequalities), [Aravind 95].

### 6. Other inequalities

[Baracca-Bergia-Livi-Restignoli 76] (for non-dichotomic observables), [Cirel'son 80] (while Bell's inequalities give limits for the correlations in local hidden variables theories, Cirel'son inequality gives the upper limit for *quantum* correlations and, therefore, the highest possible violation of Bell's inequalities according to QM; see also [Cheffles-Barnett 96]), [Hardy 92 d], [Eberhard 93], [Peres 98 d] (comparing the strengths of various Bell's inequalities) [Peres 98 f] (Bell's inequalities for any number of observers, alternative setups and outcomes).

### 7. Inequalities to detect genuine $n$ -particle nonseparability

[Svetlichny 87], [Gisin-Bechmann Pasquinucci 98], [Collins-Gisin-Popescu-(+2) 02], [Seevinck-Svetlichny 02], [Mitchell-Popescu-Roberts 02], [Seevinck-Uffink 02] (sufficient conditions for three-particle entanglement and their tests in recent experiments), [Cereceda 02 b], [Uffink 02] (quadratic Bell inequalities which distinguish, for systems of  $n > 2$  qubits, between fully entangled states and states in which at most  $n - 1$  particles are entangled).

### 8. Herbert's proof of Bell's theorem

[Herbert 75], [Stapp 85 a], [Mermin 89 a], [Penrose 89] (pp. 573-574 in the Spanish version), [Ballentine 90 a] (p. 440).

### 9. Mermin's statistical proof of Bell's theorem

[Mermin 81 a, b], [Kunstatter-Trainor 84] (in the context of the statistical interpretation of QM), [Mermin 85] (see also the comments —seven—), [Penrose 89] (pp. 358-360 in the Spanish version), [Vogt 89], [Mermin 90 e] (Chaps. 10-12), [Allen 92], [Townsend 92] (Chap. 5, p. 136), [Yurke-Stoler 92 b] (experimental proposal with two independent sources of particles), [Marmet 93].

### G. Bell's theorem without inequalities

#### 1. Greenberger-Horne-Zeilinger's proof

[Greenberger-Horne-Zeilinger 89, 90], [Mermin 90 a, b, d, 93 a, b], [Greenberger-Horne-Shimony-Zeilinger 90], [Clifton-Redhead-Butterfield 91 a, b], [Pagonis-Redhead-Clifton 91] (with  $n$  particles), [Clifton-Pagonis-Pitowsky 92], [Stapp 93 a], [Cereceda 95] (with  $n$  particles), [Pagonis-Redhead-La Rivière 96], [Belnap-Szabó 96], [Bernstein 99] (simple version of the GHZ argument), [Vaidman 99 b] (variations on the GHZ proof), [Cabello 01 a] (with  $n$  spin- $s$  particles), [Massar-Pironio 01] (GHZ for position and momentum), [Chen-Zhang 01] (GHZ for continuous variables), [Khrennikov 01 a], [Kaszlikowski-Żukowski 01] (GHZ for  $N$  quNits), [Greenberger 02] (the history of the GHZ paper), [Cerf-Massar-Pironio 02] (GHZ for many qudits).

#### 2. Peres' proof of impossibility of recursive elements of reality

[Peres 90 b, 92 a], [Mermin 90 d, 93 a, b], [Nogueira-dos Aidos-Caldeira-Domingos 92], (why Bohm's theory eludes Peres's and Mermin's proofs:) [Dewdney 92], [Dewdney 92] (see also [Pagonis-Clifton 95]), [Peres 93 a] (Sec. 7. 3), [Cabello 95], [De Baere 96 a] (how to avoid the proof).

#### 3. Hardy's proof

[Hardy 92 a, 93], [Clifton-Niemann 92] (Hardy's argument with two spin- $s$  particles), [Pagonis-Clifton 92] (Hardy's argument with  $n$  spin- $\frac{1}{2}$  particles), [Hardy-Squires 92], [Stapp 92] (Sec. VII), [Vaidman 93], [Goldstein 94 a], [Mermin 94 a, c, 95 a], [Jordan 94 a, b], (nonlocality of a single photon:) [Hardy 94, 95 a, 97]; [Cohen-Hiley 95 a, 96], [Garuccio 95 b], [Wu-Xie 96] (Hardy's argument for three spin- $\frac{1}{2}$  particles), [Pagonis-Redhead-La Rivière 96], [Kar 96], [Kar 97 a, c] (mixed states of three or more spin- $\frac{1}{2}$  particles allow a Hardy argument), [Kar

**97 b**] (uniqueness of the Hardy state for a fixed choice of observables), [**Stapp 97**], [**Unruh 97**], [**Boschi-Branca-De Martini-Hardy 97**] (ladder argument), [**Schafir 98**] (Hardy’s argument in the many-worlds and consistent histories interpretations), [**Ghosh-Kar 98**] (Hardy’s argument for two spin  $s$  particles), [**Ghosh-Kar-Sarkar 98**] (Hardy’s argument for three spin- $\frac{1}{2}$  particles), [**Cabello 98 a**] (ladder proof without probabilities for two spin  $s \geq 1$  particles), [**Barnett-Chefles 98**] (nonlocality without inequalities for all pure entangled states using generalized measurements which perform unambiguous state discrimination between non-orthogonal states), [**Cereceda 98, 99 b**] (generalized probability for Hardy’s nonlocality contradiction), [**Cereceda 99 a**] (the converse of Hardy’s theorem), [**Cereceda 99 c**] (Hardy-type experiment for maximally entangled states and the problem of subensemble postselection), [**Cabello 00 b**] (nonlocality without inequalities has not been proved for maximally entangled states), [**Yurke-Hillery-Stoler 99**] (position-momentum Hardy-type proof), [**Wu-Zong-Pang 00**] (Hardy’s proof for GHZ states), [**Hillery-Yurke 01**] (upper and lower bounds on maximal violation of local realism in a Hardy-type test using continuous variables), [**Irvine-Hodelin-Simon-Bouwmeester 04**] (realisation of [**Hardy 92 a**]).

#### 4. *Bell’s theorem without inequalities for EPR-Bohm-Bell states*

[**Cabello 01 c, d**], [**Nisticò 01**] (GHZ-like proofs are impossible for pairs of qubits), [**Aravind 02, 04**], [**Chen-Pan-Zhang-(+2) 03**] (experimental implementation).

#### 5. *Other algebraic proofs of no-local hidden variables*

[**Pitowsky 91 b, 92**], [**Herbut 92**], [**Clifton-Pagonis-Pitowsky 92**], [**Cabello 02 a**].

#### 6. *Classical limits of no-local hidden variables proofs*

[**Sanz 90**] (Chap. 4), [**Pagonis-Redhead-Clifton 91**] (GHZ with  $n$  spin- $\frac{1}{2}$  particles), [**Peres 92 b**], [**Clifton-Niemann 92**] (Hardy with two spin- $s$  particles), [**Pagonis-Clifton 92**] (Hardy with  $n$  spin- $\frac{1}{2}$  particles).

## H. Other “nonlocalities”

### 1. *“Nonlocality” of a single particle*

[**Grangier-Roger-Aspect 86**], [**Grangier-Potasek-Yurke 88**], [**Tan-Walls-Collett 91**], [**Hardy 91 a, 94, 95 a**], [**Santos 92 a**], [**Czachor**

**94**], [**Peres 95 b**], [**Home-Agarwal 95**], [**Gerry 96 c**], [**Steinberg 98**] (single-particle nonlocality and conditional measurements), [**Resch-Lundeen-Steinberg 01**] (experimental observation of nonclassical effects on single-photon detection rates), [**Björk-Jonsson-Sánchez Soto 01**] (single-particle nonlocality and entanglement with the vacuum), [**Srikanth 01 e**], [**Hessmo-Usachev-Heydari-Björk 03**] (experimental demonstration of single photon “nonlocality”).

### 2. *Violations of local realism exhibited in sequences of measurements (“hidden nonlocality”)*

[**Popescu 94, 95 b**] (Popescu notices that the LHV model proposed in [**Werner 89**] does not work for sequences of measurements), [**Gisin 96 a, 97**] (for two-level systems nonlocality can be revealed using filters), [**Peres 96 e**] (Peres considers collective tests on Werner states and uses consecutive measurements to show the impossibility of constructing LHV models for some processes of this kind), [**Berndl-Teufel 97**], [**Cohen 98 b**] (unlocking hidden entanglement with classical information), [**Żukowski-Horodecki-Horodecki-Horodecki 98**], [**Hiroshima-Ishizaka 00**] (local and nonlocal properties of Werner states), [**Kwiat-Barraza López-Stefanov-Gisin 01**] (experimental entanglement distillation and ‘hidden’ non-locality), [**Wu-Zong-Pang-Wang 01 b**] (Bell’s inequality for Werner states).

### 3. *Local immeasurability or indistinguishability (“nonlocality without entanglement”)*

[**Bennett-DiVincenzo-Fuchs-(+5) 99**] (an unknown member of a product basis cannot be reliably distinguished from the others by local measurements and classical communication), [**Bennett-DiVincenzo-Mor-(+3) 99**], [**Horodecki-Horodecki-Horodecki 99 d**] (“nonlocality without entanglement” is an EPR-like incompleteness argument rather than a Bell-like proof), [**Groisman-Vaidman 01**] (nonlocal variables with product states eigenstates), [**Walgate-Hardy 02**], [**Horodecki-Sen De-Sen-Horodecki 03**] (first operational method for checking indistinguishability of orthogonal states by LOCC; any full basis of an arbitrary number of systems is not distinguishable, if at least one of the vectors is entangled), [**De Rinaldis 03**] (method to check the LOCC distinguishability of a complete product bases).

## I. Experiments on Bell’s theorem

### 1. *Real experiments*

[**Kocher-Commins 67**], [**Papaliolios 67**], [**Freedman-Clauser 72**] (with photons correlated



in polarizations after the decay  $J = 0 \rightarrow 1 \rightarrow 0$  of Ca atoms; see also [Freedman 72], [Clauser 92]), [Holt-Pipkin 74] (id. with Hg atoms; the results of this experiment agree with Bell's inequalities), [Clauser 76 a], [Clauser 76 b] (Hg), [Fry-Thompson 76] (Hg), [Lamehi Rachti-Mittig 76] (low energy proton-proton scattering), [Aspect-Grangier-Roger 81] (with Ca photons and one-channel polarizers; see also [Aspect 76]), [Aspect-Grangier-Roger 82] (Ca and two-channel polarizers), [Aspect-Dalibard-Roger 82] (with optical devices that change the orientation of the polarizers during the photon's flight; see also [Aspect 83]), [Perrie-Duncan-Beyer-Kleinpopp 85] (with correlated photons simultaneously emitted by metastable deuterium), [Shih-Alley 88] (with a parametric-down converter), [Rarity-Tapster 90 a] (with momentum and phase), [Kwiat-Vareka-Hong-(+2) 90] (with photons emitted by a non-linear crystal and correlated in a double interferometer; following Franson's proposal [Franson 89]), [Ou-Zou-Wang-Mandel 90] (id.), [Ou-Pereira-Kimble-Peng 92] (with photons correlated in amplitude), [Tapster-Rarity-Owens 94] (with photons in optical fibre), [Kwiat-Mattle-Weinfurter-(+3) 95] (with a type-II parametric-down converter), [Strekalov-Pittman-Sergienko-(+2) 96], [Tittel-Brendel-Gisin-(+3) 97, 98] (testing quantum correlations with photons 10 km apart in optical fibre), [Tittel-Brendel-Zbinden-Gisin 98] (a Franson-type test of Bell's inequalities by photons 10,9 km apart), [Weihs-Jennewein-Simon-(+2) 98] (experiment with strict Einstein locality conditions, see also [Aspect 99]), [Kuzmich-Walmsley-Mandel 00], [Rowe-Kielinski-Meyer-(+4) 01] (experimental violation of a Bell's inequality for two beryllium ions with nearly perfect detection efficiency), [Howell-Lamas Linares-Bouwmeester 02] (experimental violation of a spin-1 Bell's inequality using maximally-entangled four-photon states), [Moehring-Madsen-Blinov-Monroe 04] (experimental Bell inequality violation with an atom and a photon; see also [Blinov-Moehring-Duan-Monroe 04]).

## 2. Proposed gedanken experiments

[Lo-Shimony 81] (disociation of a metastable molecule), [Horne-Zeilinger 85, 86, 88] (particle interferometers), [Horne-Shimony-Zeilinger 89, 90 a, b] (id.) (see also [Greenberger-Horne-Zeilinger 93], [Wu-Xie-Huang-Hsia 96]), [Franson 89] (with position and time), with observables with a discrete spectrum and —simultaneously— observables with a continuous spectrum [Żukowski-Zeilinger 91] (polarizations and momentums), (experimental proposals on Bell's inequalities without additional assumptions:) [Fry-Li 92], [Fry 93, 94], [Fry-Walther-Li 95], [Kwiat-Eberhard-Steinberg-Chiao 94], [Pittman-Shih-Sergienko-Rubin 95], [Fernández Huelga-

Ferrero-Santos 94, 95] (proposal of an experiment with photon pairs and detection of the recoiled atom), [Freyberger-Aravind-Horne-Shimony 96].

## 3. EPR with neutral kaons

[Lipkin 68], [Six 77], [Selleri 97], [Bramon-Nowakowski 99], [Ancochea-Bramon-Nowakowski 99] (Bell-inequalities for  $K^0\bar{K}^0$  pairs from  $\Phi$ -resonance decays), [Dalitz-Garbarino 00] (local realistic theories for the two-neutral-kaon system), [Gisin-Go 01] (EPR with photons and kaons: Analogies), [Hiesmayr 01] (a generalized Bell's inequality for the  $K^0\bar{K}^0$  system), [Bertlmann-Hiesmayr 01] (Bell's inequalities for entangled kaons and their unitary time evolution), [Garbarino 01], [Bramon-Garbarino 02 a, b].

## 4. Reviews

[Clauser-Shimony 78], [Pipkin 78], [Duncan-Kleinpopp 88], [Chiao-Kwiat-Steinberg 95] (review of the experiments proposed by these authors with photons emitted by a non-linear crystal after a parametric down conversion).

## 5. Experimental proposals on GHZ proof, preparation of GHZ states

[Żukowski 91 a, b], [Yurke-Stoler 92 a] (three-photon GHZ states can be obtained from three spatially separated sources of one photon), [Reid-Munro 92], [Wódkiewicz-Wang-Eberly 93] (preparation of a GHZ state with a four-mode cavity and a two-level atom), [Klyshko 93], [Shih-Rubin 93], [Wódkiewicz-Wang-Eberly 93 a, b], [Hnilo 93, 94], [Cirac-Zoller 94] (preparation of singlets and GHZ states with two-level atoms and a cavity), [Fleming 95] (with only one particle), [Pittman 95] (preparation of a GHZ state with four photons from two sources of pairs), [Haroche 95], [Laloë 95], [Gerry 96 b, d, e] (preparations of a GHZ state using cavities), [Pfau-Kurtsiefer-Mlynek 96], [Zeilinger-Horne-Weinfurter-Żukowski 97] (three-particle GHZ states prepared from two entangled pairs), [Lloyd 97 b] (a GHZ experiment with mixed states), [Keller-Rubin-Shih-Wu 98], [Keller-Rubin-Shih 98 b], [Laflamme-Knill-Zurek-(+2) 98] (real experiment to produce three-particle GHZ states using nuclear magnetic resonance), [Lloyd 98 a] (microscopic analogs of the GHZ experiment), [Pan-Zeilinger 98] (GHZ states analyzer), [Larsson 98 a] (necessary and sufficient conditions on detector efficiencies in a GHZ experiment), [Munro-Milburn 98] (GHZ in nondegenerate parametric oscillation via phase measurements), [Rarity-Tapster 99] (three-particle entanglement obtained from

entangled photon pairs and a weak coherent state), [Bouwmeester-Pan-Daniell-(+2) 99] (experimental observation of polarization entanglement for three spatially separated photons, based on the idea of [Zeilinger-Horne-Weinfurter-Żukowski 97]), [Watson 99 a], [Larsson 99 b] (detector efficiency in the GHZ experiment), [Sakaguchi-Ozawa-Amano-Fukumi 99] (microscopic analogs of the GHZ experiment on an NMR quantum computer), [Guerra-Retamal 99] (proposal for atomic GHZ states via cavity quantum electrodynamics), [Pan-Bouwmeester-Daniell-(+2) 00] (experimental test), [Nelson-Cory-Lloyd 00] (experimental GHZ correlations using NMR), [de Barros-Suppès 00 b] (inequalities for dealing with detector inefficiencies in GHZ experiments), [Cohen-Brun 00] (distillation of GHZ states by selective information manipulation), [Żukowski 00] (an analysis of the “wrong” events in the Innsbruck experiment shows that they cannot be described using a local realistic model), [Sackett-Kielpinski-King-(+8) 00] (experimental entanglement of four ions: Coupling between the ions is provided through their collective motional degrees of freedom), [Zeng-Kuang 00 a] (preparation of GHZ states via Grover’s algorithm), [Acín-Jané-Dür-Vidal 00] (optimal distillation of a GHZ state), [Cen-Wang 00] (distilling a GHZ state from an arbitrary pure state of three qubits), [Zhao-Yang-Chen-(+2) 03 b] (non-locality with a polarization-entangled four-photon GHZ state).

#### 6. Experimental proposals on Hardy’s proof

[Hardy 92 d] (with two photons in overlapping optical interferometers), [Yurke-Stoler 93] (with two identical fermions in overlapping interferometers and using Pauli’s exclusion principle), [Hardy 94] (with a source of just one photon), [Freyberger 95] (two atoms passing through two cavities), [Torgerson-Branning-Mandel 95], [Torgerson-Branning-Monken-Mandel 95] (first real experiment, measuring two-photon coincidence), [Garuccio 95 b] (to extract conclusions from experiments like the one by Torgerson et al. some inequalities must be derived), [Cabello-Santos 96] (criticism of the conclusions of the experiment by Torgerson et al.), [Torgerson-Branning-Monken-Mandel 96] (reply), [Mandel 97] (experiment), [Boschi-De Martini-Di Giuseppe 97], [Di Giuseppe-De Martini-Boschi 97] (second real experiment), [Boschi-Branca-De Martini-Hardy 97] (real experiment based on the ladder version of Hardy’s argument), [Kwiat 97 a, b], [White-James-Eberhard-Kwiat 99] (nonmaximally entangled states: Production, characterization, and utilization), [Franke-Huget-Barnett 00] (Hardy state correlations for two trapped ions), [Barbieri-De Martini-Di Nepi-Mataloni 04] (experiment of Hardy’s “ladder theorem” without “supplementary assumptions”), [Irvine-Hodelin-Simon-Bouwmeester

04] (realisation of [Hardy 92 a]).

#### 7. Some criticisms of the experiments on Bell’s inequalities. Loopholes

[Marshall-Santos-Selleri 83] (“local realism has not been refuted by atomic cascade experiments”), [Marshall-Santos 89], [Santos 91, 96], [Santos 92 c] (local hidden variable model which agree with the predictions of QM for the experiments based on photons emitted by atomic cascade, like those of Aspect’s group), [Garuccio 95 a] (criticism for the experiments with photons emitted by parametric down conversion), [Basoalto-Percival 01] (a computer program for the Bell detection loophole).

## II. “INTERPRETATIONS”

### A. Copenhagen interpretation

[Bohr 28, 34, 35 a, b, 39, 48, 49, 58 a, b, 63, 86, 96, 98] ([Bohr 58 b] was regarded by Bohr as his clearest presentation of the observational situation in QM. In it he asserts that QM cannot exist without classical mechanics: The classical realm is an essential part of any proper measurement, that is, a measurement whose results can be communicated in plain language. The wave function represents, in Bohr’s words, “a purely symbolic procedure, the unambiguous physical interpretation of which in the last resort requires a reference to a complete experimental arrangement”), [Heisenberg 27, 30, 55 a, b, 58, 95] ([Heisenberg 55 a] is perhaps Heisenberg’s most important and complete statement of his views: The wave function is “objective” but it is not “real”, the cut between quantum and classical realms cannot be pushed so far that the entire compound system, including the observing apparatus, is cut off from the rest of the universe. A connection with the external world is essential. Stapp points out in [Stapp 72] that “Heisenberg’s writings are more direct [than Bohr’s]. But his way of speaking suggests a subjective interpretation that appears quite contrary to the apparent intention of Bohr”. See also more precise differences between Bohr and Heisenberg’s writings pointed out in [DeWitt-Graham 71]), [Fock 31] (textbook), [Landau-Lifshitz 48] (textbook), [Bohm 51] (textbook), [Hanson 59], [Stapp 72] (this reference is described in [Ballentine 87 a], p. 788 as follows: ‘In attempting to save “the Copenhagen interpretation” the author radically revises what is often, rightly or wrongly, understood by that term. That interpretation in which Von Neumann’s “reduction” of the state vector in measurement forms the core is rejected, as are Heisenberg’s subjectivistic statements. The very “pragmatic” (one could also say “instrumentalist”) aspect of the interpretation is emphasized.’), [Faye 91] (on Bohr’s interpreta-

tion of QM), [Zeilinger 96 b] (“It is suggested that the objective randomness of the individual quantum event is a necessity of a description of the world (...). It is also suggested that the austerity of the Copenhagen interpretation should serve as a guiding principle in a search for deeper understanding.”), [Zeilinger 99 a] (the quotations are not in their original order, and some italics are mine: “We have knowledge, i.e., information, of an object only through observation (...). Any physical object can be described by a set of true propositions (...). [B]y proposition we mean something which can be verified directly by experiment (...). In order to analyze the information content of elementary systems, we (...) decompose a system (...) into constituent systems (...). [E]ach such constituent systems will be represented by fewer propositions. How far, then, can this process of subdividing a system go? (...). [T]he limit is reached when an individual system finally represents the truth value to one single proposition *only*. Such a system we call an elementary system. We thus suggest a principle of quantization of information as follows: *An elementary system represents the truth value of one proposition.* [This is what Zeilinger proposes as the foundational principle for quantum mechanics. He says that he personally prefers the Copenhagen interpretation because of its extreme austerity and clarity. However, the purpose of this paper is to attempt to go significantly beyond previous interpretations] (...). The spin of [a spin-1/2] (...) particle carries the answer to one question *only*, namely, the question What is its spin along the  $z$ -axis? (...). Since this is the only information the spin carries, measurement along any other direction must necessarily contain an element of randomness (...). We have thus found a reason for the irreducible randomness in quantum measurement. It is the simple fact that an elementary system cannot carry enough information to provide definite answers to all questions that could be asked experimentally (...). [After the measurement, t]he new information the system now represents has been spontaneously *created* in the measurement itself (...). [The information carried by composite systems can be distributed in different ways: E]ntanglement results if all possible information is exhausted in specifying *joint* (...) [true propositions] of the constituents”. See II G), [Fuchs-Peres 00 a, b] (quantum theory needs no “interpretation”).

## B. De Broglie’s “pilot wave” and Bohm’s “causal” interpretations

### 1. General

[Bohm 52], [de Broglie 60], [Goldberg-Schey-Schwartz 67] (computer-generated motion pictures of one-dimensional quantum-mechanical transmission and reflection phenomena), [Philippidis-Dewdney-Hiley 79] (the quantum potential and the ensemble of particle trajectories are computed and illustrated for the

two-slit interference pattern), [Bell 82], [Bohm-Hiley 82, 89], [Dewdney-Hiley 82], [Dewdney-Holland-Kyprianidis 86, 87], [Bohm-Hiley 85], [Bohm-Hiley-Kaloyerou 87], [Dewdney 87, 92, 93], [Dewdney-Holland-Kyprianidis-Vigier 88], [Holland 88, 92], [Englert-Scully-Süssmann-Walther 93 a, b] ([Dürr-Fusseder-Goldstein-Zanghì 93]) [Albert 92] (Chap. 7), [Dewdney-Malik 93], [Bohm-Hiley 93] (book), [Holland 93] (book), [Albert 94], [Pagonis-Clifton 95], [Cohen-Hiley 95 b] (comparison between Bohmian mechanics, standard QM and consistent histories interpretation), [Mackman-Squires 95] (retarded Bohm model), [Berndl-Dürr-Goldstein-Zanghì 96], [Goldstein 96, 99], [Cushing-Fine-Goldstein 96] (collective book), [García de Polavieja 96 a, b, 97 a, b] (causal interpretation in phase space derived from the coherent space representation of the Schrödinger equation), [Kent 96 b] (consistent histories and Bohmian mechanics), [Rice 97 a], [Hiley 97], [Deotto-Ghirardi 98] (there are infinite theories similar to Bohm’s —with trajectories— which reproduce the predictions of QM), [Dickson 98], [Terra Cunha 98], [Wiseman 98 a] (Bohmian analysis of momentum transfer in welcher Weg measurements), [Blaut-Kowalski Glikman 98], [Brown-Sjöqvist-Bacciagaluppi 99] (on identical particles in de Broglie-Bohm’s theory), [Leavens-Sala Mayato 99], [Griffiths 99 b] (Bohmian mechanics and consistent histories), [Maroney-Hiley 99] (teleportation understood through the Bohm interpretation), [Belousek 00 b], [Neumaier 00] (Bohmian mechanics contradict quantum mechanics), [Ghose 00 a, c, d, 01 b] (incompatibility of the de Broglie-Bohm theory with quantum mechanics), [Marchildon 00] (no contradictions between Bohmian and quantum mechanics), [Barrett 00] (surreal trajectories), [Nogami-Toyama-Dijk 00], [Shifren-Akis-Ferry 00], [Ghose 00 c] (experiment to distinguish between de Broglie-Bohm and standard quantum mechanics), [Golshani-Akhavan 00, 01 a, b, c] (experiment which distinguishes between the standard and Bohmian quantum mechanics), [Hiley-Maroney 00] (consistent histories and the Bohm approach), [Hiley-Callaghan-Maroney 00], [Gr”ossing 00] (book; extension of the de Broglie-Bohm interpretation into the relativistic regime for the Klein-Gordon case), [Dürr 01] (book), [Marchildon 01] (on Bohmian trajectories in two-particle interference devices), [John 01 a, b] (modified de Broglie-Bohm theory closer to classical Hamilton-Jacobi theory), [Bandyopadhyay-Majumdar-Home 01], [Struyve-De Baere 01], [Ghose-Majumdar-Guha-Sau 01] (Bohmian trajectories for photons), [Shojai-Shojai 01] (problems raised by the relativistic form of de Broglie-Bohm theory), [Allori-Zanghì 01 a], (de Broglie’s pilot wave theory for the Klein-Gordon equation:) [Horton-Dewdney 01 b], [Horton-Dewdney-Ne’eman 02]; [Ghose-Samal-Datta 02] (Bohmian picture of Rydberg atoms), [Feligioni-Panella-Srivastava-Widom

02], [Grübl-Rheinberger 02], [Dewdney-Horton 02] (relativistically invariant extension), [Allori-Dürr-Goldstein-Zanghì 02], [Bacciagaluppi 03] (derivation of the symmetry postulates for identical particles from pilot-wave theories), [Tumulka 04 a].

## 2. Tunneling times in Bohmian mechanics

[Hauge-Stovneng 89] (TT: A critical review), [Spiller-Clarck-Prance-Prance 90], [Olkhovsky-Recami 92] (recent developments in TT), [Leavens 93, 95, 96, 98], [Leavens-Aers 93], [Landauer-Martin 94] (review on TT), [Leavens-Iannaccone-McKinnon 95], [McKinnon-Leavens 95], [Cushing 95 a] (are quantum TT a crucial test for the causal program?; reply: [Bedard 97]), [Oriols-Martín-Suñe 96] (implications of the noncrossing property of Bohm trajectories in one-dimensional tunneling configurations), [Abolhasani-Golshani 00] (TT in the Copenhagen interpretation; due to experimental limitations, Bohmian mechanics leads to same TT), [Majumdar-Home 00] (the time of decay measurement in the Bohm model), [Ruseckas 01] (tunneling time determination in standard QM), [Stomphorst 01, 02], [Chuprikov 01].

### C. “Relative state”, “many worlds”, and “many minds” interpretations

[Everett 57 a, b, 63], [Wheeler 57], [DeWitt 68, 70, 71 b], [Cooper-Van Vechten 69] (proof of the unobservability of the splits), [DeWitt-Graham 73], [Graham 71], [Ballentine 73] (the definition of the “branches” is dependent upon the choice of representation; the assumptions of the many-worlds interpretation are neither necessary nor sufficient to derive the Born statistical formula), [Clarke 74] (some additional structures must be added in order to determine which states will determine the “branching”), [Healey 84] (critical discussion), [Geroch 84], [Whitaker 85], [Deutsch 85 a, 86] (testable split observer experiment), [Home-Whitaker 87] (quantum Zeno effect in the many-worlds interpretation), [Tipler 86], [Squires 87 a, b] (the “many-views” interpretation), [Whitaker 89] (on Squires’ many-views interpretation), [Albert-Loewer 88], [Ben Dov 90 b], [Kent 90], [Albert-Loewer 91 b] (many minds interpretation), [Vaidman 96 c, 01 d], [Lockwood 96] (many minds), [Cassinello-Sánchez Gómez 96] (and [Cassinello 96], impossibility of deriving the probabilistic postulate using a frequency analysis of infinite copies of an individual system), [Deutsch 97] (popular review), [Schafir 98] (Hardy’s argument in the many-worlds and in the consistent histories interpretations), [Dickson 98], [Tegmark 98] (many worlds or many words?), [Barrett 99 a], [Wallace 01 b], [Deutsch 01] (structure of the multiverse), [Butterfield 01], [Bacciagaluppi 01 b], [Hewitt-Horsman

03] (status of the uncertainty relations in the many worlds interpretation).

### D. Interpretations with explicit collapse or dynamical reduction theories (spontaneous localization, nonlinear terms in Schrödinger equation, stochastic theories)

[de Broglie 56], [Bohm-Bub 66 a], [Nelson 66, 67, 85], [Pearle 76, 79, 82, 85, 86 a, b, c, 89, 90, 91, 92, 93, 99 b, 00], [Bialynicki Birula-Mycielski 76] (add a nonlinear term to the Schrödinger equation in order to keep wave packets from spreading beyond any limit. Experiments with neutrons, [Shull-Atwood-Arthur-Horne 80] and [Gähler-Klein-Zeilinger 81], have resulted in such small upper limits for a possible nonlinear term of a kind that some quantum features would survive in a macroscopic world), [Dohrn-Guerra 78], [Dohrn-Guerra-Ruggiero 79] (relativistic Nelson stochastic model), [Davidson 79] (a generalization of the Fenyès-Nelson stochastic model), [Shimony 79] (proposed neutron interferometer test of some nonlinear variants), [Bell 84], [Gisin 84 a, b, 89], [Ghirardi-Rimini-Weber 86, 87, 88], [Werner 86], [Primas 90 b], [Ghirardi-Pearle-Rimini 90], [Ghirardi-Grassi-Pearle 90 a, b], [Weinberg 89 a, b, c, d] (nonlinear variant), [Peres 89 d] (nonlinear variants violate the second law of thermodynamics, (in Weinberg’s attempt faster than light communication is possible:)) [Gisin 90], [Polchinski 91], [Mielnik 00]; [Bollinger-Heinzen-Itano-(+2) 89] (tests Weinberg’s variant), [Wódkiewicz-Scully 90]), [Ghirardi 91, 95, 96], [Jordan 93 b] (fixes the Weinberg variant), [Ghirardi-Weber 97], [Squires 92 b] (if the collapse is a physical phenomenon it would be possible to measure its velocity), [Gisin-Percival 92, 93 a, b, c], [Pearle-Squires 94] (nucleon decay experimental results could be considered to rule out the collapse models, and support a version in which the rate of collapse is proportional to the mass), [Pearle 97 a] explicit model of collapse, “true collapse”, versus interpretations with decoherence, “false collapse”, [Pearle 97 b] (review of Pearle’s own contributions), [Bacciagaluppi 98 b] (Nelsonian mechanics), [Santos-Escobar 98], [Ghirardi-Bassi 99], [Pearle-Ring-Collar-Avignone 99], [Pavon 99] (derivation of the wave function collapse in the context of Nelson’s stochastic mechanics), [Adler-Brun 01] (generalized stochastic Schrödinger equations for state vector collapse), [Brody-Hughston 01] (experimental tests for stochastic reduction models).

### E. Statistical (or ensemble) interpretation

[Ballentine 70, 72, 86, 88 a, 90 a, b, 95 a, 96, 98], [Peres 84 a, 93], [Pavičić 90 d] (formal difference between the Copenhagen and the statistical interpreta-

tion), [Home-Whitaker 92].

### F. “Modal” interpretations

[van Fraassen 72, 79, 81, 91 a, b], [Cartwright 74], [Kochen 85], [Healey 89, 93, 98 a], [Dieks 89, 94, 95], [Lahti 90] (polar decomposition and measurement), [Albert-Loewer 91 a] (the Kochen-Healey-Dieks interpretations do not solve the measurement problem), [Arntzenius 90], [Albert 92] (appendix), [Elby 93 a], [Bub 93], [Albert-Loewer 93], [Elby-Bub 94], [Dickson 94 a, 95 a, 96 b, 98], [Vermaas-Dieks 95] (generalization of the MI to arbitrary density operators), [Bub 95], [Cassinelli-Lahti 95], [Clifton 95 b, c, d, e, 96, 00 b], [Bacciagaluppi 95, 96, 98 a, 00], [Bacciagaluppi-Hemmo 96, 98 a, 98 b], [Vermaas 96], [Vermaas 97, 99 a] (no-go theorems for MI), [Zimba-Clifton 98], [Busch 98 a], [Dieks-Vermaas 98], [Dickson-Clifton 98] (collective book), [Bacciagaluppi-Dickson 99] (dynamics for MI), [Dieks 00] (consistent histories and relativistic invariance in the MI), [Spekkens-Sipe 01 a, b], [Bacciagaluppi 01 a] (book), [Gambetta-Wiseman 04] (modal dynamics extended to include POVMs).

### G. “It from bit”

[Wheeler 78, 81, 95] (the measuring process creates a “reality” that did not exist objectively before the intervention), [Davies-Brown 86] (“the game of the 20 questions”, pp. 23-24 [pp. 38-39 in the Spanish version], Chap. 4), [Wheeler-Ford 98] ([p. 338:] “A measurement, in this context, is an irreversible act in which uncertainty collapses to certainty. It is the link between the quantum and the classical worlds, the point where what *might* happen (...) is replaced by what *does* happen (...).” [p. 338:] “No elementary phenomenon, he [Bohr] said, is a phenomenon until it is a registered phenomenon”. [pp. 339-340:] “Measurement, the act of turning potentiality into actuality, is an act of choice, choice among possible outcomes”. [pp. 340-341:] “Trying to wrap my brain around this idea of information theory as the basis of existence, I came up with the phrase “it from bit.” The universe an all that it contains (“it”) may arise from the myriad yes-no choices of measurement (the “bits”). Niels Bohr wrestled for most of his life with the question of how acts of measurement (or “registration”) may affect reality. It is registration (...) that changes potentiality into actuality. I build only a little on the structure of Bohr’s thinking when I suggest that we may never understand this strange thing, the quantum, until we understand how information may underlie reality. Information may not be just what we *learn* about the world. It may be what *makes* the world.

An example of the idea of it from bit: When a photon is absorbed, and thereby “measured”—until its absorption,

it had no true reality—an unsplittable bit of information is added to what we know about the word, *and*, at the same time that bit of information determines the structure of one small part of the world. It *creates* the reality of the time and place of that photon’s interaction”).

### H. “Consistent histories” (or “decoherent histories”)

[Griffiths 84, 86 a, b, c, 87, 93 a, b, 95, 96, 97, 98 a, b, c, 99, 01], [Omnès 88 a, 88 b, 88 c, 89, 90 a, b, 91, 92, 94 a, b, 95, 97, 99 a, b, 01, 02], [Gell-Mann-Hartle 90 a, 90 b, 91, 93, 94], [Gell-Mann 94] (Chap. 11), [Halliwell 95] (review), [Diósi-Gisin-Halliwell-Percival 95], [Goldstein-Page 95], [Cohen-Hiley 95 b] (in comparison with standard QM and causal de Broglie-Bohm’s interpretation), [Cohen 95] (CH in pre- and post-selected systems), [Dowker-Kent 95, 96], [Rudolph 96] (source of critical references), [Kent 96 a, b, 97 a, 98 b, c, 00 b] (CH approach allows contrary inferences to be made from the same data), [Isham-Linden-Savidou-Schreckenberg 97], [Griffiths-Hartle 98], [Brun 98], [Schafir 98 a] (Hardy’s argument in the many-world and CH interpretations), [Schafir 98 b], [Halliwell 98, 99 a, b, 00, 01, 03 a, b], [Dass-Joglekar 98], [Peruzzi-Rimini 98] (incompatible and contradictory retrodictions in the CH approach), [Nisticò 99] (consistency conditions for probabilities of quantum histories), [Rudolph 99] (CH and POV measurements), [Stapp 99 c] (nonlocality, counterfactuals, and CH), [Bassi-Ghirardi 99 a, 00 a, b] (decoherent histories description of reality cannot be considered satisfactory), [Griffiths-Omnès 99], [Griffiths 00 a, b] (there is no conflict between CH and Bell, and Kochen-Specker theorems), [Dieks 00] (CH and relativistic invariance in the modal interpretation), [Egusquiza-Muga 00] (CH and quantum Zeno effect), [Clarke 01 a, b], [Hiley-Maroney 00] (CH and the Bohm approach), [Sokolovski-Liu 01], [Raptis 01], [Nisticò-Beneduci 02], [Bar-Horwitz 02], [Brun 03], [Nisticò 03].

### I. Decoherence and environment induced superselection

[Simonius 78] (first explicit treatment of decoherence due to the environment and the ensuing symmetry breaking and “blocking” of otherwise not stable states), [Zurek 81 a, 82, 91 c, 93, 97, 98 a, 00 b, 01, 02, 03 b, c], [Joos-Zeh 85], [Zurek-Paz 93 a, b, c], [Wightman 95] (superselection rules), [Elby 94 a, b], [Giulini-Kiefer-Zeh 95] (symmetries, superselection rules, and decoherence), [Giulini-Joos-Kiefer-(+3) 96] (review, almost exhaustive source of references, [Davidovich-Brune-Raimond-Haroche 96], [Brune-Hagley-Dreyer-(+5) 96] (ex-

periment, see also [Haroche-Raimond-Brune 97], [Zeh 97, 98, 99], [Yam 97] (non-technical review), [Dugić 98] (necessary conditions for the occurrence of the “environment-induced” superselection rules), [Habib-Shizume-Zurek 98] (decoherence, chaos and the correspondence principle), [Kiefer-Joos 98] (decoherence: Concepts and examples), [Paz-Zurek 99] (environment induced superselection of energy eigenstates), [Giulini 99, 00], [Joos 99], [Bene-Borsanyi 00] (decoherence within a single atom), [Paz-Zurek 00], [Anastopoulos 00] (frequently asked questions about decoherence), [Kleckner-Ron 01], [Braun-Haake-Strunz 01], [Eisert-Plenio 02 b] (quantum Brownian motion does not necessarily create entanglement between the system and its environment; the joint state of the system and its environment may be separable at all times).

#### J. Time symmetric formalism, pre- and post-selected systems, “weak” measurements

[Aharonov-Bergman-Lebowitz 64], [Albert-Aharonov-D’Amato 85], [Bub-Brown 86] (comment: [Albert-Aharonov-D’Amato 86]), [Vaidman 87, 96 d, 98 a, b, e, 99 a, c, d, 03 b], [Vaidman-Aharonov-Albert 87], [Aharonov-Albert-Casher-Vaidman 87], [Busch 88], [Aharonov-Albert-Vaidman 88] (comments: [Leggett 89], [Peres 89 a]; reply: [Aharonov-Vaidman 89]), [Golub-Gähler 89], [Ben Menahem 89], [Duck-Stevenson-Sudarshan 89], [Sharp-Shanks 89], [Aharonov-Vaidman 90, 91], [Knight-Vaidman 90], [Hu 90], [Zachar-Alter 91], [Sharp-Shanks 93] (the rise and fall of time-symmetrized quantum mechanics; counterfactual interpretation of the ABL rule leads to results that disagree with standard QM; see also [Cohen 95]), [Peres 94 a, 95 d] (comment: [Aharonov-Vaidman 95]), [Mermin 95 b] (BKS theorem puts limits to the “magic” of retrodiction), [Cohen 95] (counterfactual use of the ABL rule), [Cohen 98 a], [Reznik-Aharonov 95], [Herbut 96], [Miller 96], [Kastner 98 a, b, 99 a, b, c, 02, 03], [Lloyd-Slotine 99], [Metzger 00], [Mohrhoff 00 d], [Aharonov-Englert 01], [Englert-Aharonov 01], [Aharonov-Botero-Popescu-(+2) 01] (Hardy’s paradox and weak values), [Atmanspacher-Römer-Walach 02].

#### K. The transactional interpretation

[Cramer 80, 86, 88], [Kastner 04].

#### L. The Ithaca interpretation: Correlations without correlata

[Mermin 98 a, b, 99 a], [Cabello 99 a, c], [Jordan 99], [McCall 01], [Fuchs 03 a] (Chaps. 18, 33),

[Plotnitsky 03].

### III. COMPOSITE SYSTEMS, PREPARATIONS, AND MEASUREMENTS

#### A. States of composite systems

##### 1. Schmidt decomposition

[Schmidt 07 a, b], [von Neumann 32] (Sec. VI. 2), [Furry 36 a, b], [Jauch 68] (Sec. 11. 8), [Balentine 90 a] (Sec. 8. 3), [Albrecht 92] (Secs. II, III and Appendix), [Barnett-Phoenix 92], [Albrecht 93] (Sec. II and Appendix), [Peres 93 a] (Chap. 5), [Elby-Bub 94] (uniqueness of triorthogonal decomposition of pure states), [Albrecht 94] (Appendix), [Mann-Sanders-Munro 95], [Ekert-Knight 95], [Peres 95 c] (Schmidt decomposition of higher order), [Aravind 96], [Linden-Popescu 97] (invariances in Schmidt decomposition under local transformations), [Acín-Andrianov-Costa-(+3) 00] (Schmidt decomposition and classification of three-quantum-bit pure states), [Terhal-Horodecki 00] (Schmidt number for density matrices), [Higuchi-Sudbery 00], [Carteret-Higuchi-Sudbery 00] (multipartite generalisation of the Schmidt decomposition), [Pati 00 c] (existence of the Schmidt decomposition for tripartite system under certain condition).

##### 2. Entanglement measures

[Barnett-Phoenix 91] (“index of correlation”), [Shimony 95], [Bennett-DiVincenzo-Smolín-Wootters 96] (for a mixed state), [Popescu-Röhrlich 97 a], [Schulman-Mozyrsky 97], [Vedral-Plenio-Rippin-Knight 97], [Vedral-Plenio-Jacobs-Knight 97], [Vedral-Plenio 98 a], [DiVincenzo-Fuchs-Mabuchi-(+3) 98], [Belavkin-Ohya 98], [Eisert-Plenio 99] (a comparison of entanglement measures), [Vidal 99 a] (a measure of entanglement is defended which quantifies the probability of success in an optimal local conversion from a single copy of a pure state into another pure state), [Parker-Bose-Plenio 00] (entanglement quantification and purification in continuous-variable systems), [Virmani-Plenio 00] (various entanglement measures do not give the same ordering for all quantum states), [Horodecki-Horodecki-Horodecki 00 a] (limits for entanglement measures), [Henderson-Vedral 00] (relative entropy of entanglement and irreversibility), [Benatti-Narnhofer 00] (on the additivity of entanglement formation), [Rudolph 00 b], [Nielsen 00 c] (one widely used method for defining measures of entanglement violates that dimensionless quantities do not depend on the system of units being used), [Brylinski 00] (algebraic measures of entanglement), [Wong-Christensen 00], [Vollbrecht-Werner

00] (entanglement measures under symmetry), [Hwang-Ahn-Hwang-Lee 00] (two mixed states such that their ordering depends on the choice of entanglement measure cannot be transformed, with unit efficiency, to each other by any local operations), [Audenaert-Verstraete-De Bie-De Moor 00], [Bennett-Popescu-Rohrlich-(+2) 01] (exact and asymptotic measures of multipartite pure state entanglement), [Majewski 01], [Życzkowski-Bengtsson 01] (relativity of pure states entanglement), [Abouraddy-Saleh-Sergienko-Teich 01] (any pure state of two qubits may be decomposed into a superposition of a maximally entangled state and an orthogonal factorizable one. Although there are many such decompositions, the weights of the two superposed states are unique), [Vedral-Kashefi 01] (uniqueness of entanglement measure and thermodynamics), [Vidal-Werner 02] (a computable measure of entanglement), [Eisert-Audenaert-Plenio 02], [Heydari-Björk-Sánchez Soto 03] (for two qubits), [Heydari-Björk 04 a, b] (for two and  $n$  qudits of different dimensions).

### 3. Separability criteria

[Peres 96 d, 97 a, 98 a] (positive partial transposition (PPT) criterion), [Horodecki-Horodecki-Horodecki 96 c], [Horodecki 97], [Busch-Lahti 97], [Sanpera-Tarrach-Vidal 97, 98], [Lewenstein-Sanpera 98] (algorithm to obtain the best separable approximation to the density matrix of a composite system. This method gives rise to a condition of separability and to a measure of entanglement), [Cerf-Adami-Gingrich 97], [Aravind 97], [Majewski 97], [Dür-Cirac-Tarrach 99] (separability and distillability of multipartite systems), [Caves-Milburn 99] (separability of various states for  $N$  qutrits), [Duan-Giedke-Cirac-Zoller 00 a] (inseparability criterion for continuous variable systems), [Simon 00 b] (Peres-Horodecki separability criterion for continuous variable systems), [Dür-Cirac 00 a] (classification of multiqubit mixed states: Separability and distillability properties), [Wu-Chen-Zhang 00] (a necessary and sufficient criterion for multipartite separable states), [Wang 00 b], [Karnas-Lewenstein 00] (optimal separable approximations), [Terhal 01] (review of the criteria for separability), [Chen-Liang-Li-Huang 01 a] (necessary and sufficient condition of separability of any system), [Eggeling-Vollbrecht-Wolf 01] ([Chen-Liang-Li-Huang 01 a] is a reformulation of the problem rather than a practical criterion; reply: [Chen-Liang-Li-Huang 01 b]), [Pittenger-Rubin 01], [Horodecki-Horodecki-Horodecki 01 b] (separability of  $n$ -particle mixed states), [Giedke-Kraus-Lewenstein-Cirac 01] (separability criterion for all bipartite Gaussian states), [Kummer 01] (separability for two qubits), [Albeverio-Fei-Goswami 01] (separability of rank two quantum states), [Wu-Anandan 01] (three necessary separability criteria for bipartite mixed

states), [Rudolph 02], [Doherty-Parrilo-Spedalieri 02, 04], [Fei-Gao-Wang-(+2) 02], [Chen-Wu 02] (generalized partial transposition criterion for separability of multipartite quantum states).

### 4. Multipartite entanglement

[Elby-Bub 94] (uniqueness of triorthogonal decomposition of pure states), [Linden-Popescu 97], [Clifton-Feldman-Redhead-Wilce 97], [Linden-Popescu 98 a], [Thapliyal 99] (tripartite pure-state entanglement), [Carteret-Linden-Popescu-Sudbery 99], [Fivel 99], [Sackett-Kielpinski-King-(+8) 00] (experimental four-particle entanglement), [Carteret-Sudbery 00] (three-qubit pure states are classified by means of their stabilizers in the group of local unitary transformations), [Acín-Andrianov-Costa-(+3) 00] (Schmidt decomposition and classification of three-qubit pure states), [Acín-Andrianov-Jané-Tarrach 00] (three-qubit pure-state canonical forms), [van Loock-Braunstein 00 b] (multipartite entanglement for continuous variables), [Wu-Zhang 01] (multipartite pure-state entanglement and the generalized GHZ states), [Brun-Cohen 01] (parametrization and distillability of three-qubit entanglement).

### 5. Entanglement swapping

[Yurke-Stoler 92 a] (entanglement from independent particle sources), [Bennett-Brassard-Crépeau-(+3) 93] (teleportation), [Żukowski-Zeilinger-Horne-Ekert 93] (event-ready-detectors), [Bose-Vedral-Knight 98] (multipartite generalization of ES), [Pan-Bouwmeester-Weinfurter-Zeilinger 98] (experimental ES: Entangling photons that have never interacted), [Bose-Vedral-Knight 99] (purification via ES), [Peres 99 b] (delayed choice for ES), [Kok-Braunstein 99] (with the current state of technology, event-ready detections cannot be performed with the experiment of [Pan-Bouwmeester-Weinfurter-Zeilinger 98]), [Polkinghorne-Ralph 99] (continuous variable ES), [Żukowski-Kaszlikowski 00 a] (ES with parametric down conversion sources), [Hardy-Song 00] (ES chains for general pure states), [Shi-Jiang-Guo 00 c] (optimal entanglement purification via ES), [Bouda-Bužžek 01] (ES between multi-qudit systems), [Fan 01 a, b], [Son-Kim-Lee-Ahn 01] (entanglement transfer from continuous variables to qubits), [Karimipour-Bagherinezhad-Bahraminasab 02 a] (ES of generalized cat states), [de Riedmatten-Marcikic-van Houwelingen-(+3) 04] (long distance ES with photons from separated sources).

### 6. Entanglement distillation (concentration and purification)

(Entanglement concentration: How to create, using only LOCC, maximally entangled pure states from not maximally entangled ones. Entanglement purification: How to distill pure maximally entangled states out of mixed entangled states. Entanglement distillation means both concentration or purification) [Bennett-Bernstein-Popescu-Schumacher 95] (concentrating partial entanglement by local operations), [Bennett 95 b], [Bennett-Brassard-Popescu-(+3) 96], [Deutsch-Ekert-Jozsa-(+3) 96], [Murao-Plenio-Popescu-(+2) 98] (multiparticle EP protocols), [Rains 97, 98 a, b], [Horodecki-Horodecki 97] (positive maps and limits for a class of protocols of entanglement distillation), [Kent 98 a] (entangled mixed states and local purification), [Horodecki-Horodecki-Horodecki 98 b, c, 99 a], [Vedral-Plenio 98 a] (entanglement measures and EP procedures), [Cirac-Ekert-Macchiavello 99] (optimal purification of single qubits), [Dür-Briegel-Cirac-Zoller 99] (quantum repeaters based on EP), [Giedke-Briegel-Cirac-Zoller 99] (lower bounds for attainable fidelity in EP), [Opatrny-Kurizki 99] (optimization approach to entanglement distillation), [Bose-Vedral-Knight 99] (purification via entanglement swapping), [Dür-Cirac-Tarrach 99] (separability and distillability of multiparticle systems), [Parker-Bose-Plenio 00] (entanglement quantification and EP in continuous-variable systems), [Dür-Cirac 00 a] (classification of multiqubit mixed states: Separability and distillability properties), [Brun-Caves-Schack 00] (EP of unknown quantum states), [Acín-Jané-Dür-Vidal 00] (optimal distillation of a GHZ state), [Cen-Wang 00] (distilling a GHZ state from an arbitrary pure state of three qubits), [Lo-Popescu 01] (concentrating entanglement by local actions—beyond mean values), [Kwiat-Barraza López-Stefanov-Gisin 01] (experimental entanglement distillation), [Shor-Smolín-Terhal 01] (evidence for non-additivity of bipartite distillable entanglement), [Pan-Gasparoni-Ursin-(+2) 03] (experimental entanglement purification of arbitrary unknown states, *Nature*).

### 7. Disentanglement

[Ghirardi-Rimini-Weber 87] (D of wave functions), [Chu 98] (is it possible to disentangle an entangled state?), [Peres 98 b] (D and computation), [Mor 99] (D while preserving all local properties), [Bandyopadhyay-Kar-Roy 99] (D of pure bipartite quantum states by local cloning), [Mor-Terno 99] (sufficient conditions for a D), [Hardy 99 b] (D and teleportation), [Ghosh-Bandyopadhyay-Roy-(+2) 00] (optimal universal D for two-qubit states), [Bužek-Hillery 00] (disentangles), [Zhou-Guo 00 a] (D and inseparability correlation in a two-qubit system).

### 8. Bound entanglement

[Horodecki 97], [Horodecki-Horodecki-Horodecki 98 b, 99 a] (a BE state is an entangled mixed state from which no pure entanglement can be distilled), [Bennett-DiVincenzo-Mor-(+3) 99] (unextendible incomplete product bases provide a systematic way of constructing BE states), [Linden-Popescu 99] (BE and teleportation), [Bruß-Peres 00] (construction of quantum states with BE), [Shor-Smolín-Thapliyal 00], [Horodecki-Lewenstein 00] (is BE for continuous variables a rare phenomenon?), [Smolin 01] (four-party unlockable BE state,  $\rho_S = \frac{1}{4} \sum_{i=1}^4 |\phi_i\rangle\langle\phi_i| \otimes |\phi_i\rangle\langle\phi_i|$ , where  $\phi_i$  are the Bell states), [Murao-Vedral 01] (remote information concentration—the reverse process to quantum teleportation—using Smolin’s BE state), [Gruska-Imai 01] (survey, p. 57), [Werner-Wolf 01 a] (BE Gaussian states), [Sanpera-Bruß-Lewenstein 01] (Schmidt number witnesses and BE), [Kaszlikowski-Żukowski-Gnaniński 02] (BE admits a local realistic description), [Augusiak-Horodecki 04] (some four-qubit bound entangled states can maximally violate two-setting Bell inequality; this entanglement does not allow for secure key distillation, so neither entanglement nor violation of Bell inequalities implies quantum security; it is also pointed out how that kind of bound entanglement can be useful in reducing communication complexity), [Bandyopadhyay-Ghosh-Roychowdhury 04] (systematic method for generating bound entangled states in any bipartite system), [Zhong 04].

### 9. Entanglement as a catalyst

[Jonathan-Plenio 99 b] (using only LOCC one cannot transform  $|\phi_1\rangle$  into  $|\phi_2\rangle$ , but with the assistance of an appropriate entangled state  $|\psi\rangle$  one can transform  $|\phi_1\rangle$  into  $|\phi_2\rangle$  using LOCC in such a way that the state  $|\psi\rangle$  can be returned back after the process:  $|\psi\rangle$  serves as a catalyst for otherwise impossible transformation), [Barnum 99] (quantum secure identification using entanglement and catalysis), [Jensen-Schack 00] (quantum authentication and key distribution using catalysis), [Zhou-Guo 00 c] (basic limitations for entanglement catalysis), [Daftuar-Klimesh 01 a] (mathematical structure of entanglement catalysis), [Anspach 01] (two-qubit catalysis in a four-state pure bipartite system).

#### B. State determination, state discrimination, and measurement of arbitrary observables

##### 1. State determination, quantum tomography

[von Neumann 31], [Gale-Guth-Trammell 68] (determination of the quantum state), [Park-



Margenau 68], [Band-Park 70, 71, 79], [Park-Band 71, 80, 92], [Brody-Meister 96] (strategies for measuring identically prepared particles), [Hradil 97] (quantum state estimation), [Raymer 97] (quantum tomography, review), [Freyberger-Bardroff-Leichtle-(+2) 97] (quantum tomography, review), [Cheffles-Barnett 97 c] (entanglement and unambiguous discrimination between non-orthogonal states), [Hradil-Summhammer-Rauch 98] (quantum tomography as normalization of incompatible observations).

2. *Generalized measurements, positive operator-valued measurements (POVMs), discrimination between non-orthogonal states*

[Neumark 43, 54] (representation of a POVM by a projection-valued measure—a von Neumann measure—in an extended higher dimensional Hilbert space; see also [Nagy 90]), [Berberian 66] (mathematical theory of POVMs), [Jauch-Piron 67] (POVMs are used in a generalized analysis of the localizability of quantum systems), [Holevo 72, 73 c, 82], [Benioff 72 a, b, c], [Ludwig 76] (POVMs), [Davies-Lewis 70] (analysis of quantum observables in terms of POVMs), [Davies 76, 78], [Helstrom 76], [Ivanovic 81, 83, 93], [Ivanovic 87] (how discriminate *unambiguously* between a pair of non-orthogonal pure states—the procedure has less than unit probability of giving an answer at all—), [Dieks 88], [Peres 88 b] (IDP: Ivanovic-Dieks-Peres measurements), [Peres 90 a] (Neumark’s theorem), [Peres-Wootters 91] (optimal detection of quantum information), [Busch-Lahti-Mittelstaedt 91], [Bennett 92 a] (B92 quantum key distribution scheme: Using two nonorthogonal states), [Peres 93 a] (Secs. 9. 5 and 9. 6), [Busch-Grabowski-Lahti 95], [Ekert-Huttner-Palma-Peres 94] (application of IDP to eavesdropping), [Massar-Popescu 95] (optimal measurement procedure for an *infinite* number of identically prepared two-level systems: Construction of an infinite POVM), [Jaeger-Shimony 95] (extension of the IDP analysis to two states with *a priori* unequal probabilities), [Huttner-Muller-Gautier-(+2) 96] (experimental unambiguous discrimination of nonorthogonal states), [Fuchs-Peres 96], [Lütkenhaus 96] (POVMs and eavesdropping), [Brandt-Myers 96, 99] (optical POVM receiver for quantum cryptography), [Grossman 96] (optical POVM; see appendix A of [Brandt 99 b]), [Myers-Brandt 97] (optical implementations of POVMs), [Brandt-Myers-Lomonaco 97] (POVMs and eavesdropping), [Fuchs 97] (nonorthogonal quantum states maximize classical information capacity), [Biham-Boyer-Brassard-(+2) 98] (POVMs and eavesdropping), [Derka-Bužek-Ekert 98] (explicit construction of an optimal *finite* POVM for two-level systems), [Latorre-Pascual-Tarrach 98] (optimal, finite, *minimal* POVMs for the cases of two to seven copies of a two-level system), [Barnett-Cheffles 98] (application

of the IDP to construct a Hardy type argument for maximally entangled states), [Cheffles 98] (unambiguous discrimination between multiple quantum states), [Brandt 99 b] (review), [Nielsen-Chuang 00], [Cheffles 00 b] (overview of the main approaches to quantum state discrimination), [Sun-Hillery-Bergou 01] (optimum unambiguous discrimination between linearly independent nonorthogonal quantum states), [Sun-Bergou-Hillery 01] (optimum unambiguous discrimination between subsets of non-orthogonal states), [Peres-Terno 02].

3. *State preparation and measurement of arbitrary observables*

[Fano 57], [Fano-Racah 59], [Wichmann 63] (density matrices arising from incomplete measurements), [Newton-Young 68] (measurability of the spin density matrix), [Swift-Wright 80] (generalized Stern-Gerlach experiments for the measurement of arbitrary spin operators), [Vaidman 88] (measurability of nonlocal states), [Ballentine 90 a] (Secs. 8. 1-2, state preparation and determination), [Phoenix-Barnett 93], [Popescu-Vaidman 94] (causality constraints on nonlocal measurements), [Reck-Zeilinger-Bernstein-Bertani 94 a, b] (optical realization of any discrete unitary operator), [Cirac-Zoller 94] (theoretical preparation of two particle maximally entangled states and GHZ states with atoms), [Żukowski-Zeilinger-Horne 97] (realization of any photon observable, also for composite systems), [Weinacht-Ahn-Bucksbaum 99] (real experiment to control the shape of an atomic electron’s wavefunction), [Hladký-Drobný-Bužek 00] (synthesis of arbitrary unitary operators), [Klose-Smith-Jessen 01] (measuring the state of a large angular momentum).

4. *Stern-Gerlach experiment and its successors*

[Gerlach-Stern 21, 22 a, b], (SGI: Stern-Gerlach interferometer; a SG followed by an inverted SG:) [Bohm 51] (Sec. 22. 11), [Wigner 63] (p. 10), [Feynman-Leighton-Sands 65] (Chap. 5); [Swift-Wright 80] (generalized SG experiments for the measurement of arbitrary spin operators), (coherence loss in a SGI:) [Englert-Schwinger-Scully 88], [Schwinger-Scully-Englert 88], [Scully-Englert-Schwinger 89]; [Summhammer-Badurek-Rauch-Kischko 82] (experimental “SGI” with polarized neutrons), [Townsend 92] (SG, Chap. 1, SGI, Chap. 2), [Platt 92] (modern analysis of a SG), [Martens-de Muynck 93, 94] (how to measure the spin of the electron), [Batelaan-Gay-Schwendiman 97] (SG for electrons), [Venugopalan 97] (decoherence and Schrödinger’s-cat states in a SG experiment), [Patil 98] (SG according to QM), [Hannout-Hoyt-Kryowonos-Widom 98] (SG and quantum measurement theory), [Shirokov 98] (spin state determination using a SG), [Garraway-Stenholm

99] (observing the spin of a free electron), [Amiet-Weigert 99 a, b] (reconstructing the density matrix of a spin  $s$  through SG measurements), [Reinisch 99] (the two output beams of a SG for spin  $1/2$  particles should not show interference when appropriately superposed because an entanglement between energy level and path selection occurs), [Schonhammer 00] (SG measurements with arbitrary spin), [Gallup-Batelaan-Gay 01] (analysis of the propagation of electrons through an inhomogeneous magnetic field with axial symmetry: A complete spin polarization of the beam is demonstrated, in contrast with the semiclassical situation, where the spin splitting is blurred), [Berman-Doolen-Hammel-Tsifrinovich 02] (static SG effect in magnetic force microscopy), [Batelaan 02].

#### 5. Bell operator measurements

[Michler-Mattle-Weinfurter-Zeilinger 96] (different interference effects produce three different results, identifying two out of the four Bell states with the other two states giving the same third measurement signal), [Lütkenhaus-Calsamiglia-Suominen 99] (a never-failing measurement of the Bell operator of a two two-level bosonic system is impossible with beam splitters, phase shifters, delay lines, electronically switched linear elements, photo-detectors, and auxiliary bosons), [Vaidman-Yoran 99], [Kwiat-Weinfurter 98] (“embedded” Bell state analysis: The four polarization-entangled Bell states can be discriminated if, simultaneously, there is an additional entanglement in another degree of freedom —time-energy or momentum—), [Scully-Englert-Bednar 99] (two-photon scheme for detecting the four polarization-entangled Bell states using atomic coherence), [Paris-Plenio-Bose-(+2) 00] (nonlinear interferometric setup to unambiguously discriminate the four polarization-entangled EPR-Bell photon pairs), [DelRe-Crosignani-Di Porto 00], [Vitali-Fortunato-Tombesi 00] (with a Kerr nonlinearity), [Andersson-Barnett 00] (Bell-state analyzer with channeled atomic particles), [Tomita 00, 01] (solid state proposal), [Calsamiglia-Lütkenhaus 01] (maximum efficiency of a linear-optical Bell-state analyzer), [Kim-Kulik-Shih 01 a] (teleportation experiment of an unknown arbitrary polarization state in which nonlinear interactions are used for the Bell state measurements and in which all four Bell states can be distinguished), [Kim-Kulik-Shih 01 b] (teleportation experiment with a complete Bell state measurement using nonlinear interactions), [O’Brien-Pryde-White-(+2) 03] (experimental all-optical quantum CNOT gate), [Gasparoni-Pan-Walther-(+2) 04] (quantum CNOT with linear optics and previous entanglement), [Zhao-Zhang-Chen-(+4) 04] (experimental demonstration of a non-destructive quantum CNOT for two independent photon-qubits).

## IV. QUANTUM EFFECTS

### 6. Quantum Zeno and anti-Zeno effects

[Misra-Sudarshan 77], [Chiu-Sudarshan-Misra 77], [Peres 80 a, b], [Joos 84], [Home-Whitaker 86, 92 b, 93], [Home-Whitaker 87] (QZE in the many-worlds interpretation), [Bollinger-Itano-Heinzen-Wineland 89], [Itano-Heinzen-Bollinger-Wineland 90], [Peres-Ron 90] (incomplete collapse and partial QZE), [Petrosky-Tasaki-Prigogine 90], [Inagaki-Namiki-Tajiri 92] (possible observation of the QZE by means of neutron spin-flipping), [Whitaker 93], [Pascasio-Namiki-Badurek-Rauch 93] (QZE with neutron spin), [Agarwal-Tewori 94] (an optical realization), [Fearn-Lamb 95], [Presilla-Onofrio-Tambini 96], [Kaulakys-Gontis 97] (quantum anti-Zeno effect), [Beige-Hegerfeldt 96, 97], [Beige-Hegerfeldt-Sondermann 97], [Alter-Yamamoto 97] (QZE and the impossibility of determining the quantum state of a single system), [Kitano 97], [Schulman 98 b], [Home-Whitaker 98], [Whitaker 98 b] (interaction-free measurement and the QZE), [Gontis-Kaulakys 98], [Pati-Lawande 98], [Álvarez Estrada-Sánchez Gómez 98] (QZE in relativistic quantum field theory), [Facchi-Pascasio 98] (quantum Zeno time of an excited state of the hydrogen atom), [Wawer-Keller-Liebman-Mahler 98] (QZE in composite systems), [Mensky 99], [Lewenstein-Rzazewski 99] (quantum anti-Zeno effect), [Balachandran-Roy 00, 01] (quantum anti-Zeno paradox), [Egusquiza-Muga 00] (consistent histories and QZE), [Facchi-Gorini-Marmo-(+2) 00], [Kofman-Kurizki-Opatrný 00] (QZE and anti-Zeno effects for photon polarization dephasing), [Horodecki 01 a], [Wallace 01 a] (computer model for the QZE), [Kofman-Kurizki 01], [Militello-Messina-Napoli 01] (QZE in trapped ions), [Facchi-Nakazato-Pascasio 01], [Facchi-Pascasio 01] (QZE: Pulsed versus continuous measurement), [Fischer-Gutiérrez Medina-Raizen 01], [Wunderlich-Balzer-Toschek 01], [Facchi 02].

### 7. Reversible measurements, delayed choice and quantum erasure

[Jaynes 80], [Wickes-Alley-Jakubowicz 81] (DC experiment), [Scully-Drühl 82], [Hillery-Scully 83], [Miller-Wheeler 84] (DC), [Scully-Englert-Schwinger 89], [Ou-Wang-Zou-Mandel 90], [Scully-Englert-Walther 91] (QE, see also [Scully-Zubairy 97], Chap. 20), [Zou-Wang-Mandel 91], [Zajonc-Wang-Zou-Mandel 91] (QE), [Kwiat-Steinberg-Chiao 92] (observation of QE), [Ueda-Kitagawa 92] (example of a “logically reversible” measurement), [Royer 94] (reversible measurement on a spin- $\frac{1}{2}$  particle), [Englert-Scully-

Walther 94] (QE, review), [Kwiat-Steinberg-Chiao 94] (three QEs), [Ingraham 94] (criticism in [Aharonov-Popescu-Vaidman 95]), [Herzog-Kwiat-Weinfurter-Zeilinger 95] (complementarity and QE), [Watson 95], [Cereceda 96 a] (QE, review), [Gerry 96 a], [Mohrhoff 96] (the Englert-Scully-Walther’s experiment is a ‘DC’ experiment only in a semantic sense), [Griffiths 98 b] (DC experiments in the consistent histories interpretation), [Scully-Walther 98] (an operational analysis of QE and DC), [Dürr-Nonn-Rempe 98 a, b] (origin of quantum-mechanical complementarity probed by a “which way” experiment in an atom interferometer, see also [Knight 98], [Paul 98]), [Björk-Karlsson 98] (complementarity and QE in welcher Weg experiments), [Hackenbroich-Rosenow-Weidenmüller 98] (a mesoscopic QE), [Mohan-Luo-Kröll-Mair 98] (delayed single-photon self-interference), [Luis-Sánchez Soto 98 b] (quantum phase difference is used to analyze which-path detectors in which the loss of interference predicted by complementarity cannot be attributed to a momentum transfer), [Kwiat-Schwindt-Englert 99] (what does a quantum eraser really erase?), [Englert-Scully-Walther 99] (QE in double-slit interferometers with which-way detectors, see [Mohrhoff 99]), [Garisto-Hardy 99] (entanglement of projection and a new class of QE), [Abranyos-Jakob-Bergou 99] (QE and the decoherence time of a measurement process), [Schwindt-Kwiat-Englert 99] (nonerasing QE), [Kim-Yu-Kulik-(+2) 00] (a DC QE), [Tsegaye-Björk-Atatüre-(+3) 00] (complementarity and QE with entangled-photon states), [Souto Ribeiro-Pádua-Monken 00] (QE by transverse indistinguishability), [Elitzur-Dolev 01] (nonlocal effects of partial measurements and QE), [Walborn-Terra Cunha-Pádua-Monken 02] (a double-slit QE), [Kim-Ko-Kim 03 b] (QE experiment with frequency-entangled photon pairs).

#### 8. Quantum nondemolition measurements

[Braginsky-Vorontsov 74], [Braginsky-Vorontsov-Khalili 77], [Thorne-Drever-Caves-(+2) 78], [Unruh 78, 79], [Caves-Thorne-Drever-(+2) 80], [Braginsky-Vorontsov-Thorne 80], [Sanders-Milburn 89] (complementarity in a NDM), [Holland-Walls-Ziller 91] (NDM of photon number by atomic-beam deflection), [Braginsky-Khalili 92] (book), [Werner-Milburn 93] (eavesdropping using NDM), [Braginsky-Khalili 96] (*Rev. Mod. Phys.*), [Friberg 97] (*Science*), [Ozawa 98 a] (nondemolition monitoring of universal quantum computers), [Karlsson-Björk-Fosberg 98] (interaction-free and NDM), [Fortunato-Tombesi-Schleich 98] (non-demolition endoscopic tomography), [Grangier-Levenson-Poizat 98] (quantum NDM in optics, review article in *Nature*), [Ban 98] (information-theoretical

properties of a sequence of NDM), [Buchler-Lam-Ralph 99] (NDM with an electro-optic feed-forward amplifier), [Watson 99 b].

#### 9. “Interaction-free” measurements

[Reninger 60] (is the first one to speak of “negative result measurements”) [Dicke 81, 86] (investigates the change in the wave function of an atom due to the non-scattering of a photon), [Hardy 92 c] (comments: [Pagonis 92], [Hardy 92 e]), [Elitzur-Vaidman 93 a, b], [Vaidman 94 b, c, 96 e, 00 b, 01 a, c], [Bennett 94], [Kwiat-Weinfurter-Herzog-(+2) 95 a, b], [Penrose 95] (Secs. 5. 2, 5. 9), [Krenn-Summhammer-Svozil 96], [Kwiat-Weinfurter-Zeilinger 96 a] (review), [Kwiat-Weinfurter-Zeilinger 96 b], [Paul-Pavičić 96, 97, 98], [Pavičić 96 a], [du Marchie van Voorthuysen 96], [Karlsson-Björk-Fosberg 97, 98] (investigates the transition from IFM of classical objects like bombs to IFM of quantum objects; in that case they are called “non-demolition measurements”), [Hafner-Summhammer 97] (experiment with neutron interferometry), [Luis-Sánchez Soto 98 b, 99], [Kwiat 98], [White-Mitchell-Nairz-Kwiat 98] (systems that allow us to obtain images from photosensible objects, obtained by absorbing or scattering fewer photons than were classically expected), [Gesztzi 98], [Noh-Hong 98], [Whitaker 98 b] (IFM and the quantum Zeno effect), [White-Kwiat-James 99], [Mirell-Mirell 99] (IFM from continuous wave multi-beam interference), [Krenn-Summhammer-Svozil 00] (interferometric information gain versus IFM), [Simon-Platzman 00] (fundamental limit on IFM), [Potting-Lee-Schmitt-(+3) 00] (coherence and IFM), [Mitchison-Jozsa 01] (IFM can be regarded as counterfactual computations), [Horodecki 01 a] (interaction-free interaction), [Mitchison-Massar 01] (IF discrimination between semi-transparent objects), [Sánchez Soto 00] (IFM and the quantum Zeno effect, review), [Kent-Wallace 01] (quantum interrogation and the safer X-ray), [Zhou-Zhou-Feldman-Guo 01 a, b] (“nondistortion quantum interrogation”), [Zhou-Zhou-Guo-Feldman 01] (high efficiency nondistortion quantum interrogation of atoms in quantum superpositions), [Methot-Wicker 01] (IFM applied to quantum computation: A new CNOT gate), [DeWeerd 02].

#### 10. Other applications of entanglement

[Wineland-Bollinger-Itano-(+2) 92] (reducing quantum noise in spectroscopy using correlated ions), [Boto-Kok-Abrams-(+3) 00] (quantum interferometric optical lithography: Exploiting entanglement to beat the diffraction limit), [Kok-Boto-Abrams-(+3) 01] (quantum lithography: Using entanglement to beat the diffraction limit), [Björk-Sánchez Soto-Søderholm

01] (entangled-state lithography: Tailoring any pattern with a single state), [D’Ariano-Lo Presti-Paris 01] (using entanglement improves the precision of quantum measurements).

## V. QUANTUM INFORMATION

### A. Quantum cryptography

#### 1. General

[Wiesner 83] (first description of quantum coding, along with two applications: making money that is in principle impossible to counterfeit, and multiplexing two or three messages in such a way that reading one destroys the others), [Bennett 84], [Bennett-Brassard 84] (BB84 scheme for quantum key distribution (QKD)), [Deutsch 85 b, 89 b], [Ekert 91 a, b, 92] (E91 scheme: QKD using EPR pairs), [Bennett-Brassard-Mermin 92] (E91 is in practice equivalent to BB84: Entanglement is not essential for QKD, and Bell’s inequality is not essential for the detection of eavesdropping), [Bennett-Brassard-Ekert 92], [Bennett 92 a] (B92 scheme: Using two nonorthogonal states), [Ekert-Rarity-Tapster-Palma 92], [Bennett-Wiesner 92], [Phoenix 93], [Muller-Breguet-Gisin 93], [Franson 93], (one-to-any QKD:) [Townsend-Smith 93], [Townsend-Blow 93], [Townsend-Phoenix-Blow-Barnett 94]; (any-to-any QKD:) [Barnett-Phoenix 94], [Phoenix-Barnett-Townsend-Blow 95]; [Barnett-Loudon-Pegg-Phoenix 94], [Franson-Ilves 94 a], [Huttner-Peres 94], [Breguet-Muller-Gisin 94], [Ekert-Palma 94], [Townsend-Thompson 94], [Rarity-Owens-Tapster 94], [Huttner-Ekert 94], [Huttner-Imoto-Gisin-Mor 95], [Hughes-Alde-Dyer-(+3) 95] (excellent review), [Phoenix-Townsend 95], [Ardehali 96] (QKD based on delayed choice), [Koashi-Imoto 96] (using two mixed states), [Hughes 97], [Townsend 97 a, 99] (scheme for QKD for several users by means of an optical fibre network), [Biham-Mor 97] (security of QC against collective attacks), [Klyshko 97], [Fuchs-Gisin-Griffiths-(+2) 97], [Brandt-Myers-Lomonaco 97], [Hughes 97 b] (relevance of quantum computation for cryptography), [Lütkenhaus-Barnett 97], [Tittel-Ribordy-Gisin 98] (review), [Williams-Clearwater 98] (book with a chapter on QC), [Mayers-Yao 98], [Slutsky-Rao-Sun-Fainman 98] (security against individual attacks), [Lo-Chau 98 b, c, 99], [Ardehali-Chau-Lo 98] (see also [Lo-Chau-Ardehali 00]), [Zeng 98 a], [Molotkov 98 c] (QC based on photon “frequency” states), [Lomonaco 98] (review), [Lo 98] (excellent review on quantum *cryptology* —the art of secure communications using quantum means—, both from the perspective of quantum *cryptography* —the art of quantum code-making— and quantum *cryptanalysis* —the

art of quantum code-breaking—), [Ribordy-Gautier-Gisin-(+2) 98] (automated ‘plug & play’ QKD), [Mitra 98], (free-space practical QC:) [Hughes-Nordholt 99], [Hughes-Buttler-Kwiat-(+4) 99], [Hughes-Buttler-Kwiat-(+5) 99]; [Lütkenhaus 99] (estimates for practical QC), [Guo-Shi 99] (QC based on interaction-free measurements), [Czachor 99] (QC with polarizing interferometers), [Kempe 99] (multipartite entanglement and its applications to QC), [Sergienko-Atature-Walton(+3) 99] (QC using parametric down-conversion), [Gisin-Wolf 99] (quantum versus classical key-agreement protocols), [Zeng 00] (QKD based on GHZ state), [Zeng-Wang-Wang 00] (QKD relied on trusted information center), [Zeng-Guo 00] (authentication protocol), [Ralph 00 a] (continuous variable QC), [Hillery 00] (QC with squeezed states), [Zeng-Zhang 00] (identity verification in QKD), [Bechmann-Pasquinucci-Peres 00] (QC with 3-state systems), [Cabello 00 c] (QKD without alternative measurements using entanglement swapping, see also [Zhang-Li-Guo 01 a], [Cabello 01 b, e]), [Bouwmeester-Ekert-Zeilinger 00] (book on quantum information), [Brassard-Lütkenhaus-Mor-Sanders 00] (limitations on practical QC), [Phoenix-Barnett-Cheffles 00] (three-state QC), [Nambu-Tomita-Chiba Kohno-Nakamura 00] (QKD using two coherent states of light and their superposition), [Cabello 00 f] (classical capacity of a quantum channel can be saturated with secret information), [Bub 01 a] (QKD using a pre- and postselected states). [Xue-Li-Guo 01, 02] (efficient QKD with nonmaximally entangled states), [Guo-Li-Shi-(+2) 01] (QKD with orthogonal product states), [Beige-Englert-Kurtsiefer-Weinfurter 01 a, b], [Gisin-Ribordy-Tittel-Zbinden 02] (review), [Long-Liu 02] (QKD in which each EPR pair carries 2 bits), [Klarreich 02] (commercial QKD: *ID Quantique, MagiQ Technologies, BBN Technologies*), [Buttler-Torgerson-Lamoreaux 02] (new fiber-based quantum key distribution schemes).

#### 2. Proofs of security

[Lo-Chau 99], [Mayers 96 b, 01, 02 a], [Biham-Boyer-Boykin-(+2) 00], [Shor-Preskill 00] (simple proof of security of the BB84), [Tamaki-Koashi-Imoto 03 a, b] (B92), [Hwang-Wang-Matsumoto-(+2) 03 a] (Shor-Preskill type security-proof without public announcement of bases), [Tamaki-Lütkenhaus 04] (B92 over a lossy and noisy channel), [Christandl-Renner-Ekert 04] (A generic security proof for QKD which can be applied to a number of different protocols. It relies on the fact that privacy amplification is equally secure when an adversary’s memory for data storage is quantum rather than classical), [Hupkes 04] (extension of the first proof for the unconditional security of the BB84 by Mayers, without the constraint that a perfect source is required).

### 3. Quantum eavesdropping

[Werner-Milburn 93], [Barnett-Huttner-Phoenix 93] (eavesdropping strategies), [Ekert-Huttner-Palma-Peres 94], [Huttner-Ekert 94], [Fuchs-Gisin-Griffiths-Niu-Peres 97], [Brandt-Myers-Lomonaco 97], [Gisin-Huttner 97], [Griffiths-Niu 97], [Cirac-Gisin 97], [Lütkenhaus-Barnett 97], [Bruß 98], [Niu-Griffiths 98 a] (optimal copying of one qubit), [Zeng-Wang 98] (attacks on BB84 protocol), [Zeng 98 b] (id.), [Bechmann Pasquinucci-Gisin 99], [Niu-Griffiths 99] (two qubit copying machine for economical quantum eavesdropping), [Brandt 99 a] (eavesdropping optimization using a positive operator-valued measure), [Lütkenhaus 00] (security against individual attacks for realistic QKD), [Hwang-Ahn-Hwang 01 b] (eavesdropper's optimal information in variations of the BB84 in the coherent attacks).

### 4. Quantum key distribution with orthogonal states

[Goldenberg-Vaidman 95 a] (QC with orthogonal states) ([Peres 96 f], [Goldenberg-Vaidman 96]), [Koashi-Imoto 97, 98 a], [Mor 98 a] (if the individual systems go one after another, there are cases in which even orthogonal states cannot be cloned), [Cabello 00 f] (QKD in the Holevo limit).

### 5. Experiments

[Bennett-Bessette-Brassard-(+2) 92] (BB84 over 32 cm through air), [Townsend-Rarity-Tapster 93 a, b], [Muller-Breguet-Gisin 93] (B92 through more than 1 km of optical fibre), [Townsend 94], [Muller-Zbinden-Gisin 95] (B92 through 22.8 km of optical fibre), [Marand-Townsend 95] (with phase-encoded photons over 30 km), [Franson-Jacobs 95], [Hughes-Luther-Morgan-(+2) 96] (with phase-encoded photons), [Muller-Zbinden-Gisin 96] (real experiment through 26 km of optical fibre), [Zbinden 98] (review of different experimental setups based on optical fibres), ('plug and play' QKD:) [Muller-Herzog-Huttner-(+3) 97], [Ribordy-Gautier-Gisin-(+2) 98]; (quantum key transmission through 1 km of atmosphere:) [Buttler-Hughes-Kwiat-(+6) 98], [Buttler-Hughes-Kwiat-(+5) 98], [Hughes-Buttler-Kwiat-(+4) 99], [Hughes-Nordholt 99] (B92 at a rate of 5 kHz and over 0.5 km in broad daylight and free space, with polarized photons), [Gisin-Brendel-Gautier-(+5) 99], [Mérola-Mazurenko-Goedgebuer-(+3) 99] (quantum cryptographic device using single-photon phase modulation), [Hughes-Morgan-Peterson 00] (48 km), [Buttler-Hughes-Lamoreaux-(+3) 00] (daylight quantum key distribution over 1.6 km),

[Jennewein-Simon-Weihs-(+2) 00] (E91 with individual photons entangled in polarization), [Naik-Peterson-White-(+2) 00] (E91 with individual photons entangled in polarization from parametric down-conversion), [Tittel-Brendel-Zbinden-Gisin 00] (with individual photons in energy-time Bell states), [Ribordy-Brendel-Gautier-(+2) 01] (long-distance entanglement-based QKD), [Stucki-Gisin-Guinnard-(+2) 02] (over 67 km with a plug & play system), [Hughes-Nordholt-Derkacs-Peterson 02] (over 10 km in daylight and at night), [Kurtsiefer-Zarda-Halder-(+4) 02] (over a free-space path of 23.4 km between the summit of Zugspitze and Karwendelspitze, *Nature*), [Waks-Inoue-Santori-(+4) 02] (quantum cryptography with a photon turnstile, *Nature*).

### 6. Commercial quantum cryptography

[ID Quantique 01], [MagiQ Technologies 02], [QinetiQ 02], [Telcordia Technologies 02], [BBN Technologies 02].

### B. Cloning and deleting quantum states

[Wootters-Zurek 82] (due to the linearity of QM, there is no *universal quantum cloner* — a device for producing two copies from an arbitrary initial state — with fidelity 1), [Dieks 82], [Herbert 82] (superluminal communication would be possible with a perfect quantum cloner), [Barnum-Caves-Fuchs-(+2) 96] (noncommuting mixed states cannot be broadcast), [Bužek-Hillery 96] (it is possible to build a cloner which produces two *approximate* copies of an arbitrary initial state, the maximum fidelity for that process is  $\frac{5}{6}$ ), [Hillery-Bužek 97] (fundamental inequalities in quantum copying), [Gisin-Massar 97] (optimal cloner which makes  $m$  copies from  $n$  copies of the original state), [Bruß-DiVincenzo-Ekert-(+2) 98] (the maximum fidelity of a universal quantum cloner is  $\frac{5}{6}$ ), [Moussa 97 b] (proposal for a cloner based on QED), [Bruß-Ekert-Macchiavello 98], [Gisin 98] ( $\frac{5}{6}$  is the maximum fidelity of a universal quantum cloner, supposing that it cannot serve for superluminal transmission of information), [Mor 98 a] (if the individual systems go one after another, there are cases in which even orthogonal states cannot be cloned), [Koashi-Imoto 98 a] (necessary and sufficient condition for two pure entangled states to be clonable by sequential access to both systems), [Westmoreland-Schumacher 98], [Mashkevich 98 b, d], [van Enk 98] (no-cloning and superluminal signaling), [Cerf 98 b] (generalization of the cloner proposed by Hillery and Bužek in case that the two copies are not identical; the inequalities that govern the fidelity of this process), [Werner 98] (optimal cloning of pure states), [Zanardi 98 b] (cloning in  $d$  dimensions), [Cerf 98 c] (asymmetric cloning), [Duan-Guo 98 c, f] (probabilistic cloning),

[Keyl-Werner 98] (judging single clones), [Bužek-Hillery 98 a, b] (universal optimal cloning of qubits and quantum registers), [Bužek-Hillery-Bednik 98], [Bužek-Hillery-Knight 98], [Chefles-Barnett 98 a, b], [Masiak-Knight 98] (copying of entangled states and the degradation of correlations), [Niu-Griffiths 98] (two qubit copying machine for economical quantum eavesdropping), [Bandyopadhyay-Kar 99], [Ghosh-Kar-Roy 99] (optimal cloning), [Hardy-Song 99] (no signalling and probabilistic quantum cloning), [Murao-Jonathan-Plenio-Vedral 99] (quantum telecloning: a process combining quantum teleportation and optimal quantum cloning from one input to  $M$  outputs), [Dür-Cirac 00 b] (telecloning from  $N$  inputs to  $M$  outputs), [Albeverio-Fei 00 a] (on the optimal cloning of an  $N$ -level quantum system), [Macchiavello 00 b] (bounds on the efficiency of cloning for two-state quantum systems), [Zhang-Li-Wang-Guo 00] (probabilistic quantum cloning via GHZ states), [Pati 00 a] (assisted cloning and orthogonal complementing of an unknown state), [Pati-Braunstein 00 a] (impossibility of deleting an unknown quantum state: If two photons are in the same initial polarization state, there is no mechanism that produces one photon in the same initial state and another in some standard polarization state), [Simon-Weihs-Zeilinger 00 a, b] (optimal quantum cloning via stimulated emission), [Cerf 00 a] (Pauli cloning), [Pati 00 b], [Zhang-Li-Guo 00 b] (cloning for  $n$ -state system), [Cerf-Ipe-Rottenberg 00] (cloning of continuous variables), [Cerf 00 b] (asymmetric quantum cloning in any dimension), [Kwek-Oh-Wang-Yeo 00] (Bužek-Hillery cloning revisited using the bures metric and trace norm), [Galvão-Hardy 00 b] (cloning and quantum computation), [Kempe-Simon-Weihs 00] (optimal photon cloning), [Cerf-Iblisdir 00] (optimal  $N$ -to- $M$  cloning of conjugate quantum variables), [Fan-Matsumoto-Wadati 01 b] (cloning of  $d$ -level systems), [Roy-Sen-Sen 01] (is it possible to clone using an arbitrary blank state?), [Bruß-Macchiavello 01 a] (optimal cloning for two pairs of orthogonal states), [Fan-Matsumoto-Wang-(+2) 01] (a universal cloner allowing the input to be arbitrary states in symmetric subspace), [Fan-Wang-Matsumoto 02] (a quantum-copying machine for equatorial qubits), [Rastegin 01 a, b, 03 a] (some bounds for quantum copying), [Cerf-Durt-Gisin 02] (cloning a qutrit), [Segre 02] (no cloning theorem versus the second law of thermodynamics), [Feng-Zhang-Sun-Ying 02] (universal and original-preserving quantum copying is impossible), [Qiu 02 c] (non-optimal universal quantum deleting machine), [Ying 02 a, b], [Han-Zhang-Guo 02 b] (bounds for state-dependent quantum cloning), [Rastegin 03 b] (limits of state-dependent cloning of mixed states), [Pati-Braunstein 03 b] (deletion of unknown quantum state against a copy can lead to superluminal signalling, but erasure of unknown quantum state does not imply faster than light signalling), [Horodecki-Horodecki-Sen De-Sen 03] (no-deleting and no-cloning principles

as consequences of conservation of quantum information), [Horodecki-Sen De-Sen 03 b] (orthogonal pure states can be cloned and deleted. However, for orthogonal mixed states deletion is forbidden and cloning necessarily produces an irreversibility, in the form of leakage of information into the environment), [Peres 02] (why wasn't the no-cloning theorem discovered fifty years earlier?).

### C. Quantum bit commitment

[Brassard-Crépeau-Jozsa-Langlois 93], [Mayers 97] (unconditionally secure QBC is impossible), [Brassard-Crépeau-Mayers-Salvail 97] (review on the impossibility of QBC), [Kent 97 b, 99 a, c, d, 00 a, 01 a, b], [Lo-Chau 96, 97, 98 a, d], [Brassard-Crépeau-Mayers-Salvail 98] (defeating classical bit commitments with a quantum computer), [Hardy-Kent 99] (cheat sensitive QBC), [Molotkov-Nazin 99 c] (unconditionally secure relativistic QBC), [Bub 00 b], [Yuen 00 b, c, 01 a, c] (unconditionally secure QBC is possible), [Nambu-Chiba Kohno 00] (information-theoretic description of no-go theorem of a QBC), [Molotkov-Nazin 01 b] (relativistic QBC) [Molotkov-Nazin 01 c] (QBC in a noisy channel), [Li-Guo 01], [Spekkens-Rudolph 01 a] (degrees of concealment and bindingness in QBC protocols), [Spekkens-Rudolph 01 b] (optimization of coherent attacks in generalizations of the BB84 QBC protocol), [Cheung 01] (QBC can be unconditionally secure), [Srikanth 01 f], [Bub 01 b] (review), [Shimizu-Imoto 02 a] (fault-tolerant simple QBC unbreakable by individual attacks), [Nayak-Shor 03] (bit-commitment-based quantum coin flipping), [Srikanth 03].

### D. Secret sharing and quantum secret sharing

[Żukowski-Zeilinger-Horne-Weinfurter 98], [Hillery-Bužek-Berthiaume 99] (one- to two-party SS and QSS using three-particle entanglement, and one- to three-party SS using four-particle entanglement), [Karlsson-Koashi-Imoto 99] (one- to two-party SS using two-particle entanglement, and QSS using three-particle entanglement), [Cleve-Gottesman-Lo 99] (in a  $(k, n)$  threshold scheme, a secret quantum state is divided into  $n$  shares such that any  $k$  shares can be used to reconstruct the secret, but any set of  $k - 1$  shares contains no information about the secret. The “no-cloning theorem” requires that  $n < 2k$ ), [Tittel-Zbinden-Gisin 99] (QSS using pseudo-GHZ states), [Smith 00] (QSS for general access structures), [Bandyopadhyay 00 b], [Gottesman 00 a] (theory of QSS), [Karimipour-Bagherinezhad-Bahraminasab 02 b] (SS).

## E. Quantum authentication

[Ljunggren-Bourennane-Karlsson 00] (authority-based user authentication in QKD), [Zeng-Guo 00] (QA protocol), [Zhang-Li-Guo 00 c] (QA using entangled state), [Jensen-Schack 00] (QA and QKD using catalysis), [Shi-Li-Liu-(+2) 01] (QKD and QA based on entangled state), [Guo-Li-Guo 01] (non-demolition measurement of nonlocal variables and its application in QA), [Curty-Santos 01 a, c], [Barnum 01] (authentication codes), [Curty-Santos-Pérez-García Fernández 02], [Kuhn 03] (QA using entanglement and symmetric cryptography), [Curty 04].

## F. Teleportation of quantum states

### 1. General

[Bennett-Brassard-Crépeau-(+3) 93], [Sudbery 93] (News and views, *Nature*), [Deutsch-Ekert 93], [Popescu 94], [Vaidman 94 a], [Davidovich-Zagury-Brune-(+2) 94], [Cirac-Parkins 94], [Braunstein-Mann 95], [Vaidman 95 c], [Popescu 95], [Gisin 96 b], [Bennett-Brassard-Popescu-(+3) 96], [Horodecki-Horodecki-Horodecki 96 b], [Horodecki-Horodecki 96 b], [Taubes 96], [Braunstein 96 a], [Home 97] (Sec. 4. 4), [Moussa 97 a], [Nielsen-Caves 97] (reversible quantum operations and their application to T), [Zheng-Guo 97 a, b], [Watson 97 b], [Anonymous 97], [Williams-Clearwater 98] (book with a chapter on T), [Brassard-Braunstein-Cleve 98] (T as a quantum computation), [Braunstein-Kimble 98 a] (T of continuous quantum variables), [Collins 98] (*Phys. Today*), [Pan-Bouwmeester-Weinfurter-Zeilinger 98], [García Alcaine 98 a] (review), [Klyshko 98 c] (on the realization and meaning of T), [Molotkov 98 a] (T of a single-photon wave packet), [de Almeida-Maia-Villas Bôas-Moussa 98] (T of atomic states with cavities), [Ralph-Lam 98] (T with bright squeezed light), [Horodecki-Horodecki-Horodecki 99 c] (general T channel, singlet fraction and quasi-distillation), [Vaidman 98 c] (review of all proposals and experiments, and T in the many-worlds interpretation), [Zubairy 98] (T of a field state), [Nielsen-Knill-Laflamme 98] (complete quantum T using nuclear magnetic resonance), [Stenholm-Bardroff 98] (T of  $N$ -dimensional states), [Karlsson-Bourennane 98] (T using three-particle entanglement), [Plenio-Vedral 98] (T, entanglement and thermodynamics), [Ralph 98] (all optical quantum T), [Maierle-Lidar-Harris 98] (T of superpositions of chiral amplitudes), [Vaidman-Yoran 99] (methods for reliable T), [Lütkenhaus-Calsamiglia-Suominen 99] (a never-failing measurement of the Bell operator in a two two-level bosonic system is impossible with beam splitters, phase shifters, delay lines, electronically

switched linear elements, photo-detectors, and auxiliary bosons), [Linden-Popescu 99] (bound entanglement and T), [Molotkov-Nazin 99 b] (on T of continuous variables), [Tan 99] (confirming entanglement in continuous variable quantum T), [Villas Bôas-de Almeida-Moussa 99] (T of a zero- and one-photon running-wave state by projection synthesis), [van Enk 99] (discrete formulation of T of continuous variables), [Milburn-Braunstein 99] (T with squeezed vacuum states), [Ryff 99], [Koniorczyk-Janszky-Kis 99] (photon number T), [Bose-Knight-Plenio-Vedral 99] (proposal for T of an atomic state via cavity decay), [Ralph-Lam-Polkinghorne 99] (characterizing T in optics), [Maroney-Hiley 99] (T understood through the Bohm interpretation), [Hardy 99 b] (a toy local theory in which cloning is not possible but T is), [Parkins-Kimble 99] (T of the wave function of a massive particle), [Marinatto-Weber 00 b] (which kind of two-particle states can be teleported through a three-particle quantum channel?), [Bouwmeester-Pan-Weinfurter-Zeilinger 00] (high-fidelity T of independent qubits), [Zeilinger 00 c], [van Loock-Braunstein 00 a] (T of continuous-variable entanglement), [Banaszek 00] (optimal T with an arbitrary pure state), [Opatrný-Kurizki-Welsch 00] (improvement on T of continuous variables by photon subtraction via conditional measurement), [Horoshko-Kilin 00] (T using quantum nondemolition technique), [Murao-Plenio-Vedral 00] (T of quantum information to  $N$  particles), [Li-Li-Guo 00] (probabilistic T and entanglement matching), [Cerf-Gisin-Massar 00] (classical T of a qubit), [DelRe-Crosgnani-Di Porto 00] (scheme for total T), [Kok-Braunstein 00 a] (postselected versus nonpostselected T using parametric down-conversion), [Bose-Vedral 00] (mixedness and T), [van Loock-Braunstein 00 b] (multipartite entanglement for continuous variables: A quantum T network), [Braunstein-D'Ariano-Milburn-Sacchi 00] (universal T with a twist), [Bouwmeester-Ekert-Zeilinger 00] (book on quantum information), [Dür-Cirac 00 b] (multipartite T), [Henderson-Hardy-Vedral 00] (two-state T), [Motyoshi 00] (T without Bell measurements), [Vitali-Fortunato-Tombesi 00] (complete T with a Kerr nonlinearity), [Galvão-Hardy 00 a] (building multiparticle states with T), [Banaszek 00 a] (optimal T with an arbitrary pure state), [Lee-Kim 00] (entanglement T via Werner states), [Lee-Kim-Jeong 00] (transfer of nonclassical features in T via a mixed quantum channel), [Żukowski 00 b] (Bell's theorem for the nonclassical part of the T process), [Clausen-Opatrný-Welsch 00] (conditional T using optical squeezers), [Grangier-Grosshans 00 a] (T criteria for continuous variables), [Koniorczyk-Kis-Janszky 00], [Gorbachev-Zhiliba-Trubilko-Yakovleva 00] (T of entangled states and dense coding using a multiparticle quantum channel), [van Loock-Braunstein 00 d] (telecloning and multiuser quantum channels for continuous variables), [Hao-Li-Guo 00]

(probabilistic dense coding and T), [Zhou-Hou-Zhang 01] (T of  $S$ -level pure states by two-level EPR states), [Trump-Bruß-Lewenstein 01] (realistic T with linear optical elements), [Werner 01 a] (T and dense coding schemes), [Ide-Hofmann-Kobayashi-Furusawa 01] (continuous variable T of single photon states), [Wang-Feng-Gong-Xu 01] (atomic-state T by using a quantum switch), [Braunstein-Fuchs-Kimble-van Loock 01] (quantum versus classical domains for T with continuous variables), [Bowen-Bose 01] (T as a depolarizing quantum channel), [Shi-Tomita 02] (T using a W state), [Agrawal-Pati 02] (probabilistic T), [Yeo 03 a] (T using a three-qubit W state), [Peres 03 b] (it includes a narrative of how Peres remembers that T was conceived).

## 2. Experiments

[Boschi-Branca-De Martini-(+2) 98] (first experiment), [Bouwmeester-Pan-Mattle-(+3) 97] (first published experiment), [Furusawa-Sørensen-Braunstein-(+3) 98], (first T of a state that describes a light field, see also [Caves 98 a]), [Sudbery 97] (News and views, *Nature*), (Comment: [Braunstein-Kimble 98 b], Reply: [Bouwmeester-Pan-Daniell-(+3) 98]), (discussion on which group did the first experiment:) [De Martini 98 a], [Zeilinger 98 a]; [Koenig 00] (on Vienna group's experiments on T), [Kim-Kulik-Shih 01 a] (T experiment of an unknown arbitrary polarization state in which nonlinear interactions are used for the Bell state measurements and in which all four Bell states can be distinguished), [Pan-Daniell-Gasparoni-(+2) 01] (four-photon entanglement and high-fidelity T), [Lombardi-Sciarrino-Popescu-De Martini 02] (T of a vacuum-one-photon qubit), [Kim-Kulik-Shih 02] (proposal for an experiment for T with a complete Bell state measurements using nonlinear interactions), [Marcikic-de Riedmatten-Tittel-(+2) 03] (experimental probabilistic quantum teleportation: Qubits carried by photons of 1.3 mm wavelength are teleported onto photons of 1.55 mm wavelength from one laboratory to another, separated by 55 m but connected by 2 km of standard telecommunications fibre, *Nature*), [Pan-Gasparoni-Aspelmeyer-(+2) 03] (*Nature*).

## G. Telecloning

[Murao-Jonathan-Plenio-Vedral 99] (quantum telecloning: a process combining quantum teleportation and optimal quantum cloning from one input to  $M$  outputs), [Dür-Cirac 00 b] (telecloning from  $N$  inputs to  $M$  outputs), [van Loock-Braunstein 00 d] (telecloning and multiuser quantum channels for continuous variables), [van Loock-Braunstein 01] (telecloning of continuous quantum variables), [Ghiu 03] (asymmetric quantum telecloning of  $d$ -level systems), [Ricci-

Sciarrino-Sias-De Martini 03 a, b] (experimental results), [Zhao-Chen-Zhang-(+3) 04] (experimental demonstration of five-photon entanglement and open-destination teleportation), [Pirandola 04] (the standard, non cooperative, telecloning protocol can be outperformed by a cooperative one).

## H. Dense coding

[Bennett-Wiesner 92] (encoding  $n^2$  values in a  $n$ -level system), [Deutsch-Ekert 93] (popular review), [Barnett-London-Pegg-Phoenix 94] (communication using quantum states), [Barenco-Ekert 95] (the Bennett-Wiesner scheme for DC based on the discrimination of the four Bell states is the optimal one, i.e. it maximizes the mutual information, even if the initial state is not a Bell state but a non-maximally entangled state), [Mattle-Weinfurter-Kwiat-Zeilinger 96] (experimental transmission of a "trit" using a two-level quantum system, with photons entangled in polarization), [Huttner 96] (popular review of the MWKZ experiment), [Cerf-Adami 96] (interpretation of the DC in terms of negative information), [Bose-Vedral-Knight 99] (Sec. V. B, generalization with several particles and several transmitters), [Bose-Plenio-Vedral 98] (with mixed states), [Shimizu-Imoto-Mukai 99] (DC in photonic quantum communication with enhanced information capacity), [Ban 99 c] (DC via two-mode squeezed vacuum state), [Bose-Plenio-Vedral 00] (mixed state DC and its relation to entanglement measures), [Fang-Zhu-Feng-Mao-Du 00] (experimental implementation of DC using nuclear magnetic resonance), [Braunstein-Kimble 00] (DC for continuous variables), [Ban 00 b, c] (DC in a noisy quantum channel), [Gorbachev-Zhiliba-Trubilko-Yakovleva 00] (teleportation of entangled states and DC using a multiparticle quantum channel), [Hao-Li-Guo 00] (probabilistic DC and teleportation), [Werner 01 a] (teleportation and DC schemes), [Hiroshima 01] (optimal DC with mixed state entanglement), [Bowen 01 a] (classical capacity of DC), [Hao-Li-Guo 01] (DC using GHZ), [Cereceda 01 b] (DC using three qubits), [Bowen 01 b], [Li-Pan-Jing-(+3) 01] (DC exploiting bright EPR beam), [Liu-Long-Tong-Li 02] (DC between multi-parties), [Grudka-Wójcik 02 a] (symmetric DC between multi-parties), [Lee-Ahn-Hwang 02], [Ralph-Huntington 02] (unconditional continuous-variable DC), [Mizuno-Wakui-Furusawa-Sasaki 04] (experimental demonstration of DC using entanglement of a two-mode squeezed vacuum state), [Schaetz-Barrett-Leibfried-(+6) 04] (experimental DC with atomic qubits).

## I. Remote state preparation and measurement

(In remote state preparation Alice knows the state which is to be remotely prepared in Bob's site with-



out sending him the qubit or the complete classical description of it. Using one bit and one ebit Alice can remotely prepare a qubit (from an special ensemble) of her choice at Bob's site. In remote state measurement Alice asks Bob to simulate any single particle measurement statistics on an arbitrary qubit [Bennett-DiVincenzo-Smolin-(+2) 01], [Pati 01 c, 02], [Srikanth 01 c], [Zeng-Zhang 02], [Berry-Sanders 03 a] (optimal RSP), [Agrawal-Parashar-Pati 03] (RSP for multiparties), [Bennett-Hayden-Leung-(+2) 02] (general method of remote state preparation for arbitrary states of many qubits, at a cost of 1 bit of classical communication and 1 bit of entanglement per qubit sent), [Shi-Tomita 02 c] (RSP of an entangled state), [Abeyesinghe-Hayden 03] (generalized RSP), [Ye-Zhang-Guo 04], [Berry 04] (resources required for exact RSP).

#### J. Classical information capacity of quantum channels

(A quantum channel is defined by the action of sending one of  $n$  possible messages, with different *a priori* probabilities, to a receiver in the form of one of  $n$  distinct density operators. The receiver can perform any generalized measurement in an attempt to discern which message was sent.) [Gordon 64], [Levitin 69, 87, 93], [Holevo 73 a, b, 79, 97 a, b, 98 a, b, c], [Yuen-Ozawa 93], [Hall-O'Rourke 93], [Jozsa-Robb-Wootters 94] (lower bound for accessible information), [Fuchs-Caves 94] (simplification of the Holevo upper bound of the maximum information extractable in a quantum channel, and upper and lower bounds for binary channels), [Hausladen-Schumacher-Westmoreland-Wootters 95], [Hausladen-Jozsa-Schumacher-(+2) 96], [Schumacher-Westmoreland-Wootters 96] (limitation on the amount of accessible information in a quantum channel), [Schumacher-Westmoreland 97].

#### K. Quantum coding, quantum data compression

[Schumacher 95] (optimal compression of quantum information carried by ensembles of pure states), [Lo 95] (quantum coding theorem for mixed states), [Horodecki 98] (limits for compression of quantum information carried by ensembles of mixed states), [Horodecki-Horodecki-Horodecki 98 a] (optimal compression of quantum information for one-qubit source at incomplete data), [Barnum-Smolin-Terhal 97, 98], [Jozsa-Horodecki-Horodecki-Horodecki 98] (universal quantum information compression), [Horodecki 00] (toward optimal compression for mixed signal states), [Barnum 00].

#### L. Reducing the communication complexity with quantum entanglement

[Yao 79], [Cleve-Buhrman 97] (substituting quantum entanglement for communication), [Cleve-Tapp 97], [Grover 97 a], [Buhrman-Cleve-van Dam 97] (two-party communication complexity problem: Alice receives a string  $x = (x_0, x_1)$  and Bob a string  $y = (y_0, y_1)$ . Each of the strings is a combination of two bit values:  $x_0, y_0 \in \{0, 1\}$  and  $x_1, y_1 \in \{-1, 1\}$ . Their common goal is to compute the function  $f(x, y) = x_1 y_1 (-1)^{x_0 y_0}$ , with as high a probability as possible, while exchanging altogether only 2 bits of information. This can be done with a probability of success of 0.85 if the two parties share two qubits in a maximally entangled state, whereas with shared random variables but without entanglement, this probability cannot exceed 0.75. Therefore, in a classical protocol 3 bits of information are necessary to compute  $f$  with a probability of at least 0.85, whereas with the use of entanglement 2 bits of information are sufficient to compute  $f$  with the same probability), [Buhrman-van Dam-Høyer-Tapp 99] (reducing the communication complexity in the "guess my number" game using a GHZ state, see also [Steane-van Dam 00] and [Gruska-Imai 01] (p. 28)), [Raz 99] (exponential separation of quantum and classical communication complexity), [Galvão 00] (experimental requirements for quantum communication complexity protocols), [Lo 00 a] (classical communication cost in distributed quantum-information processing: A generalization of quantum-communication complexity), [Klauck 00 b, 01 a], [Brassard 01] (survey), [Høyer-de Wolf 01] (improved quantum communication complexity bounds for disjointness and equality), [Xue-Li-Zhang-Guo 01] (three-party quantum communication complexity via entangled tripartite pure states), [Xue-Huang-Zhang-(+2) 01] (reducing the communication complexity with quantum entanglement), [Brukner-Żukowski-Zeilinger 02] (quantum communication complexity protocol with two entangled qutrits), [Galvão 02] (feasible quantum communication complexity protocol), [Massar 02] (closing the detection loophole and communication complexity), [Brukner-Żukowski-Pan-Zeilinger 04] (violation of Bell's inequality: Criterion for quantum communication complexity advantage).

#### M. Quantum games and quantum strategies

[Meyer 99 a] (comment: [van Enk 00]; reply: [Meyer 00 a]), [Eisert-Wilkens-Lewenstein 99] (comment: [Benjamin-Hayden 01 b]), [Marinatto-Weber 00 a] (comment: [Benjamin 00 c]; reply: [Marinatto-Weber 00 c]), [Eisert-Wilkens 00 b], [Li-Zhang-Huang-Guo 00] (quantum Monty Hall problem), [Du-Xu-Li-(+2) 00] (Nash equilibrium in QG), [Du-Li-Xu-(+3) 00] (multi-player and

multi-choice QG), [Du-Xu-Li-(+3) 00] (quantum strategy without entanglement), [Wang-Kwek-Oh 00] (quantum roulette: An extended quantum strategy), [Johnson 01] (QG with a corrupted source), [Benjamin-Hayden 01 a], [Du-Xu-Li-(+2) 01] (entanglement playing a dominating role in QG), [Du-Li-Xu-(+3) 01 a] (quantum battle of the sexes), [Kay-Johnson-Benjamin 01] (evolutionary QG), [Parrondo 01], [Iqbal-Toor 01 a, b, c, 02 a, b, c, d, e], [Du-Li-Xu-(+4) 01] (experimental realization of QG on a quantum computer), [Piotrowski-Sladkowski 01] (bargaining QG), [Nawaz-Toor 01 a] (strategies in quantum Hawk-Dove game), [Klarreich 01] (*Nature*), [Nawaz-Toor 01 b] (worst-case payoffs in quantum battle of sexes game), [Du-Li-Xu-(+3) 01 b], [Flitney-Ng-Abbott 02] (quantum Parrondo's games), [D'Ariano-Gill-Keyl-(+3) 02] (quantum Monty Hall problem), [Chen-Kwek-Oh 02] (noisy QG), [Flitney-Abbott 02] (quantum version of the Monty Hall problem), [Han-Zhang-Guo 02 a] (GHZ and W states in quantum three-person prisoner's dilemma), [Protopopescu-Barhen 02] (solving continuous global optimization problems using quantum algorithms), [van Enk-Pike 02] (classical rules in quantum games), [Ma-Long-Deng-(+2) 02] (cooperative three- and four-player quantum games), [Meyer 02], [Du-Li-Xu-(+3) 02] (entanglement enhanced multiplayer quantum games); [Li-Du-Massar 02] (continuous-variable quantum games), [Lee-Johnson 02 b] (review), [Guinea-Martín Delgado 03] (quantum chinos game), [Chen-Hogg-Beausoleil 03] (quantum  $n$ -player public goods game), [Du-Xu-Li-(+2) 02] (playing prisoner's dilemma with quantum rules), [Gravier-Jorrand-Mhalla-Payan 03], [Özdemir-Shimamura-Morikoshi-Imoto 02] (samaritan's dilemma), [Shimamura-Özdemir-Morikoshi-Imoto 03], [Özdemir-Shimamura-Imoto 04], [Kargin 04] (coordination games).

#### N. Quantum clock synchronization

[Chuang 00], [Jozsa-Abrams-Dowling-Williams 00], [Burt-Ekstrom-Swanson 00], [Genovese-Novero 00 c] (QCS based on entangled photon pairs transmission), [Shahriar 00], [Preskill 00 b] (QCS and quantum error correction), [Hwang-Ahn-Hwang-Han 00] (entangled quantum clocks for measuring proper-time difference), [Giovannetti-Lloyd-Maccone 01 a, 02 a], [Harrelson-Kerenidis 01], [Giovannetti-Lloyd-Maccone-Wong 01], [Janzing-Beth 01 c] (quasi-order of clocks and synchronism and quantum bounds for copying timing information), [Yurtsever-Dowling 02], [Giovannetti-Lloyd-Maccone-Wong 02], [Giovannetti-Lloyd-Maccone-Shahriar 02] (limits to QCS induced by completely dephasing communication channels), [Krčo-Paul 02] (a multi-party protocol), [Valencia-Scarcelli-Shih 04].

## VI. QUANTUM COMPUTATION

### A. General

[Benioff 80, 81, 82 a, b, c, 86, 95, 96, 97 a, b, 98 a, c, d], [Feynman 82] (Feynman asked whether or not the behavior of every physical system can be simulated by a computer, taking no more time than the physical system itself takes to produce the observed behavior. Feynman suggests that it may not be possible to simulate a quantum system in real time by a classical computer whereas it may be possible with a quantum computer. So if Feynman's suggestion is correct it implies there are tasks a QC can perform far more efficiently than a classical computer), [Deutsch 85 b] (quantum equivalent of a Turing machine), [Feynman 85, 86] (physical limitations of classical computers), [Deutsch 89] (QC networks), [Deutsch 92], [Deutsch-Jozsa 92], [Bennett 93], [Brown 94] (popular review) [Sleator-Weinfurter 95], [Bennett 95 a] (review, see for more references), [Lloyd 93, 94 a, b, 95 a, b], [Shor 95] (how to reduce decoherence in QC memory), [Dove 95], [Pellizzari-Gardiner-Cirac-Zoller 95] (how to reduce decoherence in a QC based on cavities by continuous observation), [Chuang-Yamamoto 95] (a simple QC), [Glanz 95 a], [Plenio-Vedral-Knight 96] (review), [Barenco 96] (review), [Barenco-Ekert-Macchiavello-Sampera 96] (review), [Haroche-Raimond 96] (review), [Deutsch 97] (review), [Myers 97] (can a QC be fully quantum?), [Grover 97 a] (quantum telecomputation), [Bennett-Bernstein-Brassard-Vazirani 97] (strengths and weaknesses of QC), [Warren-Gershenfeld-Chuang 97] (the usefulness of NMR QC), [Williams-Clearwater 98] (book), [Hughes 98] (relevance of QC for cryptography), [Preskill 98 a, b] (pros and cons of QC), [Lo-Spiller-Popescu 98] (book), [Berman-Doolen-Mainieri-Tsifrinovich 98] (book), [Gramß 98] (book), [Milburn 98] (book), [Steane 98 b] (review), [Farhi-Gutmann 98 a] (analog analogue of a digital QC), [Loss-DiVincenzo 98], [Schack 98] (using a QC to investigate quantum chaos), [Vedral-Plenio 98 b] (review), [Buhrman-Cleve-Wigderson 98] (classical vs. quantum communication and QC), [Ekert-Fernández Huelga-Macchiavello-Cirac 98] (using entangled states to make computations between distant nodes of a quantum network), [Deutsch-Ekert 98] (review), [Scarani 98] (review), [Privman-Vagner-Kventsel 98] (QC based on a system with quantum Hall effect), [Gershenfeld-Chuang 98] (QC with molecules, review), [DiVincenzo 98 a], [Kane 98] (QC based on silicon and on RMN), [Farhi-Gutmann 98 b] (decision trees), [Linden-Fremann 98 b] (Deutsch-Jozsa algorithm on a three-qubit NMR QC), [Collins-Kim-Holton 98] (Deutsch-Jozsa algorithm as a test of QC), [Terhal-Smolín 98] (single quantum querying of a database), [Rieffel-Polak 98] (introduction for non-physicists), [Zalka 98 d]

(an introduction to QC), [Luo-Zeng 98] (NMR QC with a hyperpolarized nuclear spin bulk), [Gruska 99] (book), [Braunstein-Caves-Jozsa-Linden-Popescu-Schac 99] (separability of very noisy mixed states and implications for NMR QC), [Brun-Schac 99], [Braunstein 99] (book), [Brooks 99] (book), [Williams 99] (book), [DiVincenzo-Loss 99], [Sanders-Kim-Holton 99], [Gottesman-Chuang 99] (QC using teleportation and single-qubit operations), [Preskill 99 d] (Chap. 6), [Macchiavello-Palma-Zeilinger 00] (book of collected papers), [Lloyd 00 a] (quantum search without entanglement), [Cirac-Zoller 00] (scalable QC with ions in an array of microtraps), [Bouwmeester-Ekert-Zeilinger 00] (book on quantum information), [Bennett-DiVincenzo 00] (review in *Nature* on quantum information and QC), [Nielsen-Chuang 00] (book), [Bacon-Kempe-Lidar-Whaley 00] (universal fault-tolerant QC on decoherence-free subspaces), [Beige-Braun-Tregenna-Knight 00] (QC using dissipation to remain in a decoherence-free subspace), [Osborne 00 d], [Georgeot-Shepelyansky 00] (in the quantum chaos regime, an ideal state quickly disappears, and exponentially many states become mixed; below the quantum chaos border an ideal state can survive for long times, and can be used for QC), [Knill-Nielsen 00 a] (theory of QC), [Ekert-Hayden-Inamori 00] (basic concepts in QC), [Ekert-Hayden-Inamori-Oi 01] (what is QC), [Knill-Laflamme-Milburn 01] (scheme for efficient QC with linear optics), [Linden-Popescu 01] (entanglement is necessary for QC), [Hardy-Steeb 01] (book), [Kitaev-Shen-Vyalyi 02] (book), [Lomonaco 02] (book), [Lomonaco-Brandt 02] (book), [Zalka 02] (lectures on QC), [Biham-Brassard-Kenigsberg-Mor 03] (the Deutsch-Jozsa problem and the Simon problem can be solved using a separable state).

## B. Quantum algorithms

### 1. Deutsch-Jozsa's and Simon's

[Deutsch 85 b], [Deutsch-Jozsa 92], [Simon 94, 97], [Cleve-Ekert-Macchiavello-Mosca 98], [Chi-Kim-Lee 00 a, 01] (initialization-free generalized DJ algorithm), [Vala-Amitay-Zhan-(+2) 02] (experimental implementation of the DJ algorithm for three-qubit functions using rovibrational molecular wave packets representation), [Gulde-Riebe-Lancaster-(+6) 03] (implementation of the DJ algorithm on an ion-trap quantum computer, *Nature*), [Brazier-Plenio 03] (the DJ algorithm is surprisingly good as the problem becomes less structured and is always better than the van Dam algorithm for low numbers of queries), [Ermakov-Fung 03] (NMR implementation of the DJ algorithm using different initial states), [Bianucci-Muller-Shih-(+3) 04] (experimental realization of the one qubit DJ algorithm in a quantum dot), [Cereceda 04 c] (generalization of

the DJ algorithm using two qudits).

### 2. Factoring

[Shor 94, 97] (the number of steps any classical computer requires in order to find the prime factors of an  $l$ -digit integer increases exponentially with  $l$ , at least using algorithms known at present. Factoring large integers is therefore conjectured to be intractable classically, an observation underlying the security of widely used cryptographic codes. Quantum computer, however, could factor integers in only polynomial time, using Shor's quantum factoring algorithm), [Ekert-Jozsa 96] (*Rev. Mod. Phys.*), [Plenio-Knight 96] (realistic lower bounds for the factorization time of large numbers), [Zalka 98 c] (fast versions of Shor's factoring algorithm), [Berman-Doolen-Tsifrinovich 00] (influence of superpositional wave function oscillations on Shor's algorithm), [Lomonaco 00 b] (Shor's quantum factoring algorithm), [McAnally 01] [Vandersypen-Steffen-Breyta-(+3) 01] (experimental realization of Shor's quantum factoring algorithm using nuclear magnetic resonance, *Nature*), [Lavor-Manssur-Portugal 03] (review of Shor's factoring algorithm).

### 3. Searching

[Grover 96 b, 97 b, c, 98 a, b, c, d, 00 c, 02 b, c] (a QA for a quicker search of an item in a non-ordered  $n$  items database: While a classical algorithm requires  $\frac{n}{2}$  steps to obtain a 50% probability of success, Grover's algorithm obtains 100% success with  $\frac{\pi\sqrt{n}}{4}$  steps), [Brassard 97] (on Grover's algorithm), [Boyer-Brassard-Høyer-Tapp 96, 98] (optimal number of iterations for the amplitude of the solution state in Grover's algorithm), [Collins 97] (on Grover's algorithm and other advances in quantum computation), [Terhal-Smolín 97] (searching algorithms), [Biron-Biham-Biham-(+2) 98] (generalized Grover's algorithm), [Chuang-Gershenfeld-Kubinec 98] (experimental implementation of quantum fast search), [Ross 98] (a modification of Grover's algorithm as a fast database search), [Carlini-Hosoya 98] (an alternative algorithm for database search), [Buhrman-de Wolf 98] (lower bounds for a quantum search), [Roehrig 98] (an upper bound for searching in an ordered list), [Zalka 99 a] (Grover's algorithm is optimal), [Jozsa 99] (searching in Grover's algorithm), [Long 01] (Grover algorithm with zero theoretical failure rate), [Patel 01 a], [Li-Li 01] (a general quantum search algorithm), [Murphy 01], [Grover 01] (pedagogical article describing the invention of the quantum search algorithm), [Bae-Kwon 01], [Miao 01 a] (construction for the unsorted quantum search algorithms), [Collins 02].

#### 4. Simulating quantum systems

[Feynman 82] (Feynman asked whether or not the behavior of every physical system can be simulated by a computer, taking no more time than the physical system itself takes to produce the observed behavior. Feynman suggests that it may not be possible to simulate a quantum system in real time by a classical computer whereas it may be possible with a quantum computer. So if Feynman's suggestion is correct it implies there are tasks a QC can perform far more efficiently than a classical computer), [Feynman 86], [Lloyd 96] (Feynman's 1982 conjecture, that quantum computers can be programmed to simulate any local quantum system, is shown to be correct), [Wiesner 96] (simulations of many-body quantum systems), [Meyer 96 a, 97], [Lidar-Biham 97], [Abrams-Lloyd 97] (simulation of many-body Fermi systems on a universal quantum computer), [Zalka 98 a, b], [Boghosian-Taylor 98 a, b], [Schack 98] (using a quantum computer to investigate quantum chaos), [Somaroo-Tseng-Havel-(+2) 99] (quantum simulations on a quantum computer), [Terhal-DiVincenzo 00], [Leung 01 a], [Ortiz-Gubernatis-Knill-Laflamme 02] (simulating fermions on a quantum computer), [Somma-Ortiz-Gubernatis-(+2) 02], [Berman-Ezhov-Kamenev-Yepey 02], [Chepelianskii-Shepelyansky 02 a, b], [Wocjan-Rotteler-Janzing-Beth 02] (simulating Hamiltonians in quantum networks: Efficient schemes and complexity bounds), [Jané-Vidal-Dür-(+2) 03] (simulation of quantum dynamics with quantum optical systems), [Kraus-Hammerer-Giedke-Cirac 03] (Hamiltonian simulation in continuous-variable systems).

#### 5. Quantum random walks

[Aharonov-Davidovich-Zagury 93], [Meyer 96 a, b], [Nayak-Vishwanath 00], [Watrous 01], [Aharonov-Ambainis-Kempe-Vazirani 01], [Ambainis-Bach-Nayak-(2) 01], [Travaglione-Milburn 02 a], [Konno 02] (QRW in one dimension), [Kempe 03] (an introductory overview), [Brun-Carteret-Ambainis 03 a, b, c], [Grimmett-Janson-Scudo 03] (weak limits for quantum random walks), [Bracken-Ellinas-Tsochantjis 04].

#### 6. General and others

[Durr-Høyer 96] (a QA for finding the minimum), [Cockhott 97] (databases), [Ekert-Macchiavello 98], [Cleve-Ekert-Macchiavello-Mosca 98], [Hogg 98 a, b], [Hogg-Yanik 98] (local searching methods), [Ekert-Jozsa 98], [Pati 98 c], [Pittenger 99] (book on QA), [Abrams-Lloyd 99] (algorithm for finding eigenvalues and eigenvectors), [Ahuja-Kapoor 99] (algorithm for finding the maximum), [Watrous 00] (QA

for solvable groups), [Vandersypen-Steffen-Breyta-(+3) 00] (experimental realization of an order-finding algorithm with an NMR quantum computer), [Ivanyos-Magniez-Santha 01] (QA for some instances of the non-Abelian hidden subgroup problem), [Alber-Beth-Horodecki-(+6) 01] (Chap. 4), [Galindo-Martín Delgado 02] (review), [Shor 02 b] (introduction to QA), [Klappenecker-Rötteler 03].

#### C. Quantum logic gates

[Deutsch 89 a] (a set of gates is *universal* if any unitary action can be decomposed into a product of successive actions of these gates on different subsets of the input qubits; the *Deutsch gate* is a three-qubit universal gate), [Barenco 95] (almost any two-qubit gate is universal), [DiVincenzo 95 b] (two-qubit gates are universal for quantum computation; its classical analog is not true: classical reversible two-bit gates are not universal), [Barenco-Bennett-Cleve-(+6) 95] (one-qubit gates plus the CNOT gate are enough for quantum computation), [Cirac-Zoller 95] (proposal for a quantum computer with ions), [Monroe-Meekhof-King-(+2) 95] (ions in a radiofrequency trap), [Domokos-Raimond-Brune-Haroche 95] (they control atoms using photons trapped in superconductor cavities), [Barenco-Deutsch-Ekert-Jozsa 95] (quantum logic gates), [Schwarzschild 96] (experimental quantum logic gates), [Cory-Fahmy-Havel 97] (NMR), [Gershenfeld-Chuang 97] (NMR), (Los Alamos experiment with trapped ions:) [Hughes-James-Gómez-(+12) 98], [Wineland-Monroe-Itano-(+5) 98], [James-Gulley-Holzschneider-(+10) 98]; [Stevens-Brochard-Steane 98] (experimental methods for processors with trapped ions), [Brennen-Caves-Jessen-Deutsch 98] (optical), [Wei-Xue-Morgera 98], [Linden-Barjat-Carbajo-Freeman 98] (pulse sequences for NMR quantum computers: How to manipulate nuclear spins while freezing the motion of coupled neighbours), [Fuji 01], [Schmidt Kaler-Haffner-Riebe-(+7) 03] (experimental Cirac-Zoller CNOT quantum gate, *Nature*), [O'Brien-Pryde-White-(+2) 03] (experimental all-optical quantum CNOT gate), [Gasparoni-Pan-Walther-(+2) 04] (quantum CNOT with linear optics and previous entanglement), [Zhao-Zhang-Chen-(+4) 04] (experimental demonstration of a non-destructive quantum CNOT for two independent photon-qubits).

#### D. Schemes for reducing decoherence

[Briegel-Dür-Cirac-Zoller 98] (quantum repeaters for communication), [Duan-Guo 98 a, b, d, h] (reducing decoherence), [Viola-Lloyd 98] (dynamical suppression of decoherence in two-state quantum systems), [DiVincenzo-Terhal 98] (decoherence: The obstacle to

quantum computation, review).

### E. Quantum error correction

[Shor 95, 96] (9:1), [Steane 96 a, b, c, 98 d, e] (QEC codes) (7:1), [Calderbank-Shor 96] (QEC), [Gottesman 96], [DiVincenzo-Shor 96], [Bennett-DiVincenzo-Smolín-Wootters 96] (5:1), [Laflamme-Miquel-Paz-Zurek 96] (perfect QEC code), [Ekert-Macchiavello 96], [Schumacher-Nielsen 96], [Calderbank-Rains-Shor-Sloane 96, 97], [Chau 97 a, b], [Cleve-Gottesman 97], [Cerf-Cleve 97] (information-theoretic interpretation of QEC codes), [Knill-Laflamme 97] (QEC codes), [Plenio-Vedral-Knight 97 a, b] (QEC in the presence of spontaneous emission), [Vedral-Rippin-Plenio 97], [Chuang-Yamamoto 97], [Braunstein-Smolín 97] (perfect QEC coding in 24 laser pulses), [Braunstein 98 a, b], [Knill-Laflamme-Zurek 98 a, b] (arbitrarily high efficiency QEC codes), [Gottesman 98 a, b] (fault tolerant quantum computation), [Preskill 98 c] (brief history of QEC codes), [Preskill 98 d] (fault tolerant quantum computation), [Cory-Price-Mass-(+5) 98] (experimental QEC), [Kak 98], [Steinbach-Twamley 98] (motional QEC), [Koashi-Ueda 99] (reversing measurement and probabilistic QEC), [Chau 99], [Kanter-Saad 99] (error-correcting codes that nearly saturate Shannon's bound), [Preskill 99 d] (Chap. 7), [Knill-Laflamme-Viola 00] (theory of QEC for general noise), [Barnes-Warren 00] (automatic QEC), [Nielsen-Chuang 00] (Chap. 10), [Knill-Laflamme-Martinez-Negrevergne 01] (implementation of the five qubit error correction benchmark), [Schumacher-Westmoreland 01 b] (approximate quantum error correction), [Korepin-Terilla 02], [Yang-Chu-Han 02], [Gottesman 02] (introduction to QEC), [Ahn-Wiseman-Milburn 03] (QEC for continuously detected errors), [Pollatsek-Ruskai 03] (permutationally invariant codes for quantum error correction).

### F. Decoherence-free subspaces and subsystems

[Palma-Suominen-Ekert 96], [Duan-Guo 97 a, 98 a, e], [Zanardi-Rasetti 97 a, b], [Zanardi 97, 98, 99], [Lidar-Chuang-Whaley 98] (DFS for quantum computation), [Lidar-Bacon-Whaley 99], [Bacon-Kempe-Lidar-Whaley 00] (universal fault-tolerant quantum computation on DFS), [Lidar-Bacon-Kempe-Whaley 00, 01 a, b], [Kempe-Bacon-Lidar-Whaley 00], [Beige-Braun-Tregenna-Knight 00] (quantum computation using dissipation to remain in a DFS), [Kwiat-Berglund-Altepeter-White 00] (experimental preparation a two-photon polarization-entangled singlet state and demonstration of its invariance under collective decoherence), [Kielinski-Meyer-Rowe-(+4) 01] (experi-

mental demonstration of the protection of a qubit against collective dephasing by encoding it in two trapped ions), [Viola-Fortunato-Pravia-(+3) 01] (experimental demonstration of the protection of a qubit against collective decoherence by encoding it in a DF subsystem of three NMR qubits), [Fortunato-Viola-Hodges-(+2) 02] (experimental demonstration of the protection of a qubit against collective dephasing by encoding it two NMR qubits), [Foldi-Benedict-Czirjak 02] (preparation of DF, subradiant states in a cavity), [Feng-Wang 02 a] (quantum computing with four-particle DF states in an ion trap), [Wu-Lidar 02 b] (creating DFS using strong and fast pulses), [Cabello 02 m] (four-qubit DFS), [Satinover 02 a] (DFS in supersymmetric oscillator networks), [Satinover 02 b], [Lidar-Whaley 03] (review), [Brown-Vala-Whaley 03] (scalable ion trap quantum computation in decoherence-free subspaces with pairwise interactions only), [Ollerenshaw-Lidar-Kay 03] (Grover's search algorithm on a NMR computer in which two qubits are protected from a special kind of errors by encoding them in four qubits), [Fonseca Romero-Mokarzel-Terra Cunha-Nemes 03], [Walton-Abouraddy-Sergienko-(+2) 03 b] (DFS in QKD), [Boileau-Gottesman-Laflamme-(+2) 04] (B92 with double singlets).

### G. Experiments and experimental proposals

(Implementation of an algorithm for solving the two-bit Deutsch problem with NMR:) [Chuang-Vandersypen-Zhou-(+2) 98], [Jones-Mosca 98]; [Jones-Mosca-Hansen 98] (implementation of Grover's quantum search algorithm with NMR), [Nakamura-Pashkin-Tsai 99] (coherent control of macroscopic quantum states in a single-Cooper-pair box), [Fu-Luo-Xiao-Zeng 99] (experimental realization of a discrete Fourier transformation on an NMR QC), [Kwiat-Mitchell-Schwindt-White 99] (Grover's search algorithm: An optical approach), [Marx-Fahmy-Myers-(+2) 99] (realization of a 5-bit NMR QC using a new molecular architecture), [Yannoni-Sherwood-Vandersypen-(+3) 99] (NMR using liquid crystal solvents), [Vandersypen-Steffen-Sherwood-(+3) 00] (first implementation of a three qubit Grover's algorithm), [Jones 00 a, b] (NMR QC: A critical evaluation), [Vrijen-Yablonovitch-Wang-(+5) 00] (electron spin resonance transistors for quantum computing in silicon-germanium heterostructures), [Cory-Laflamme-Knill-(+13) 00] (NMR based quantum information processing: Achievements and prospects), [Deutsch-Brennen-Jessen 00] (QC with neutral atoms in an optical lattice), [DiVincenzo 00], [Kane 00] (silicon-based QC), [Opatrný-Kurizki 00] (QC based on photon exchange interactions), [Kielinski-Ben Kish-Britton-(+6) 01] (trapped-ion QC), [Vandersypen-Steffen-Breyta-(+3) 01] (experimental realization of Shor's quantum factoring

algorithm using nuclear magnetic resonance, *Nature*). [Gulde-Riebe-Lancaster-(+6) 03] (implementation of the Deutsch-Jozsa algorithm on an ion-trap quantum computer, *Nature*), [Steffen-van Dam-Hogg-(+2) 03] (implementation of an adiabatic quantum optimization algorithm), [Ermakov-Fung 03] (NMR implementation of the DJ algorithm using different initial states), [Brainis-Lamoureux-Cerf-(+3) 03] (fiber-optics implementation of the DJ and Bernstein-Vazirani quantum algorithms with three qubits).

## VII. MISCELLANEOUS

### A. Textbooks

[Dirac 30], [Fock 31], [von Neumann 32], [Born 33], [Landau-Lifshitz 48], [Schiff 49], [Bohm 51], [Messiah 58], [Merzbacher 61], [Feynman-Hibbs 65], [Feynman-Leighton-Sands 65], [Sakurai 67, 85], [Cohen Tannoudji-Diu-Laloë 73], [Galindo-Pascual 78], [Bohm 79], [Bransden-Joachain 89], [Greiner 89], [Pauli-Achuthan-Venkatesan 90], [Ballentine 90 a, 98], [Peres 93 a], [Isham 95], [Hecht 00], [Schwinger 01], [Bes 04].

### B. History of quantum mechanics

[Jammer 66] (the conceptual development of QM until 1927), [van der Waerden 67] (17 papers translated to English from 1916 to 1926), [Kuhn-Heilbron-Forman-Allen 67] (sources for history of QM), [Hermann 71] (1899-1913), [Kangro 72] (original on QM papers translated to English), [Jammer 74] (the philosophy of QM), [Holton 80] (133 informally collected “classic” papers in quantum physics), [Mehra-Rechenberg 82 a-e, 87 a, b, 00 a, b] (historical development of QM, 1900-1941), [Jammer 85] (the EPR problem in its historical development), [Howard 85] (Einstein, locality and separability), [Pais 86] (history of nuclear physics, quantum field theories, and subatomic particles, 1927-1983), [Icaza 91] (historical development, 1925-1927), [Marage-Wallenborn 95] (the Solvay conferences), [Sánchez Ron 01] (1860-1926), [Friedrich-Herschbach 03] (Stern and Gerlach).

### C. Biographs

[Planck 48] (autobiography), [Gerlach 48] (Planck), [Born 75] (autobiography), [Heims 80] (von Neumann), [Pais 82] (a scientific biography of Einstein), [Heilbron 86] (Planck), [Moore 89] (Schrödinger), [Jammer 88] (paper on Bohm), [Bernstein 89] (interview with Bell), [Jammer 90, 93] (papers on Bell), [Kragh 90] (Dirac), [Pais 91] (Bohr),

[MacRae 91] (von Neumann), [Cassidy 92] (Heisenberg), [Pines 93] (Bohm’s obituary), [Israel-Gasca 95] (von Neumann), [Peres 96 a, b] (Nathan Rosen 1909-95), [Bergmann-Merzbacher-Peres 96] (Obituary: Nathan Rosen), [Israelit 96] (Nathan Rosen: 1909-1995), [Peat 97] (Bohm), [Laurikainen 97] (essays on Pauli), [Wheeler-Ford 98] (Wheeler’s autobiography), [Goddard 98] (Dirac), [Whitaker 98 a] (Bell), [Mehra 99] (Einstein), [Pais 00] (biographical portraits of Bohr, Born, Dirac, Einstein, von Neumann, Pauli, Uhlenbeck, Wigner and others), [Holton 00] (Heisenberg and Einstein), [Aspect 00] (contains a photograph of J. S. Bell and A. Aspect about 1986 in Paris), [Jackiw-Shimony 02] (Bell), [Bell 02] (Bell’s wife reminiscences), [Whitaker 02] (Bell in Belfast: Early years and education), [d’Espagnat 02] (Bell), [Enz 02] (Pauli), [Schroer 03] (Jordan), [Fernández Rañada 04] (Heisenberg), [Lahera 04] (Bohr).

### D. Philosophy of the founding fathers

[Petersen 63] (Bohr’s philosophy), [Heelan 65, 75] (Heisenberg’s philosophy), [Hall 65] (philosophical basis of Bohr’s interpretation of quantum mechanics), [Folse 85] (Bohr’s philosophy), [Laurikainen 85, 88] (Pauli’s philosophy), [Fine 86] (Einstein and QM), [Honner 87] (Bohr’s philosophy), [Murdoch 87] (Bohr’s philosophy), [Faye 91] (on Bohr’s interpretation of QM), [Faye-Folse 94] (Bohr and philosophy), [Bohr 98] (collected writings beyond physics: attempts to prove that biology cannot be reduced to physics, essays on the influence on his work of philosopher Hoffding), [Jammer 99] (Einstein and religion).

### E. Quantum logic

[Birkhoff-von Neumann 36] (first QL), [Reichenbach 44] (first three-valued QL), [Putnam 57] (three-valued QL), [Mackey 63], [Finkelstein 69, 72], [Putnam 69, 74, 81], [Piron 72, 76], [van Fraassen 73, 74 b], [Scheibe 73], [Jammer 74] (Chap. 8, historical account), [Hooker 75, 79] (collections of original papers), [Suppes 76] (collective book), [Friedman-Putnam 78], [Stairs 78, 82, 83 a, b], [Greechie 78] (a nonstandard QL), [Beltrametti-Cassinelli 79] (collective book), [Beltrametti-Cassinelli 81] (book), [Beltrametti-van Fraassen 81], [Hughes 81] (paper in *Sci. Am.*), [Holdsworth-Hooke 83] (a critical survey of QL), [Redhead 87] (Chap. 7), [Pitowsky 89 a] (book), [Hughes 89] (Chap. 7), [Pykacz-Santos 90, 91, 95], [Pavičić 92 b] (bibliography on quantum logics and related structures), [Rédei 98] (book), [Svozil 98 b] (book), [Pykacz 98], [Coecke-Moore-Wilce 00], [McKay-Megill-Pavičić 00] (algorithms for Greechie diagrams), [Dalla Chiara-Giuntini 01].

## F. Superselection rules

[Wick-Wightman-Wigner 52], [Galindo-Pascual 78], [Gilmore-Park 79 a, b], [Mirman 79], [Wan 80] (superselection rules, quantum measurement and Schrödinger’s cat), [Zurek 82], [Hughes-van Fraassen 88] (can the measurement problem be solved by superselection rules?), [Giulini-Kiefer-Zeh 95], [Wightman 95], [Dugić 98], [Cisneros-Martínez y Romero-Núñez Yépez-Salas Brito 98], [Giulini 99, 00] (the distinction between ‘hard’ —i.e., those whose existence is demonstrated by means of symmetry principles— and ‘soft’ —or ‘environment-induced’— superselection rules is not well founded), [Mayers 02 b] (a charge superselection rule implies no restriction on the operations that can be executed on any individual qubit), [Kitaev-Mayers-Preskill 03] (superselection rules do not enhance the information-theoretic security of quantum cryptographic protocols), [Verstraete-Cirac 03 a] (nonlocality in the presence of superselection rules and data hiding protocols), [Schuch-Verstraete-Cirac 04 a, b] (entanglement in the presence of superselection rules), [Wiseman-Vaccaro 03] (entanglement of indistinguishable particles shared between two parties), [Wiseman-Bartlett-Vaccaro 03] (entanglement constrained by generalized superselection rules).

## H. Quantum cosmology

[Clarke 74] (quantum theory and cosmology), [Hartle-Hawking 83] (the wave function of the universe), [Tipler 86] (the many-worlds interpretation of quantum mechanics in quantum cosmology), [Hawking 87], [Sánchez Gómez 96], [Percival 98 b] (cosmic quantum measurement).

## G. Relativity and the instantaneous change of the quantum state by local interventions

[Bloch 67], [Aharonov-Albert 80, 81, 84], [Herbert 82] (superluminal communication would be possible with a perfect quantum cloner), [Pearle 86 a] (stochastic dynamical reduction theories and superluminal communication), [Squires 92 b] (explicit collapse and superluminal signals), [Peres 95 a, 00 b], [Garuccio 96], [Svetlichny 98] (quantum formalism with state-collapse and superluminal communication), [Aharonov-Reznik-Stern 98] (quantum limitations on superluminal propagation), [Mittelstaedt 98] (can EPR-correlations be used for the transmission of superluminal signals?), [Westmoreland-Schumacher 98] (entanglement and the nonexistence of superluminal signals; comments: [Mashkevich 98 b], [van Enk 98]), [Shan 99] (quantum superluminal communication does not result in the causal loop), [Aharonov-Vaidman 01], [Svozil 01], [Zbinden-Brendel-Tittel-Gisin 01] (experimental test of relativistic quantum state collapse with moving reference frames), [Buhrman-Massar 04] (any correlations more “non local” than those achievable in an EPR-Bell type experiment necessarily allow generation of entanglement; in [Bennett-Harrow-Leung-Smolín 03] it is shown that any unitary that can generate entanglement necessarily also allows signaling).

## VIII. BIBLIOGRAPHY

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