FORMATS FOR SUBMISSION OF PROJECTS

(To be filled by applicant)
{Sections 101 to 192 to be on separate sheet(s)}

101. Project Title: Studying the properties of vortices created in quantized radiation field

102. Broad Subject: Physical Sciences

103. Sub Area: ii) Lasers, Optics, Atomic and Molecular Physics

104. Duration in months : 36

105. Total cost : ₹ 11,00,000 (11 lac)

106. FE Component : NA

107. Project Category: Basic Research

111. Principal Investigator : Dr. Abir Bandyopadhyay

112. Designation : Senior Lecturer

113. Department : General Sciences

114. Institute Name : Hooghly Engineering & Technology College

115. Address : Vivekananda Rd., Pipulpati, Hooghly (WB) 712103

116. Date of Birth: 29.12.1965. **Sex** (M/~~F~~) M

117. Telephone Fax Gram e-mail : +91(33)2681 0505, +91(33)2680 3026,
abir@hetc.ac.in

118-138. NA

Project Title: Studying the properties of vortices created in quantized radiation field

Registration No.....(to be filled by DST)

Principal Investigator.....Dr. Abir Bandyopadhyay

Institution: Hooghly Engineering & Technology College

191. Project summary (maximum 150 words)

Optical vortex (OV) with helical wave front and associated orbital angular-momentum (OAM), produced in a controlled manner using computer-generated hologram, cylindrical lens mode converter, and spiral phase plate, find a variety of applications in optical manipulation, communication, quantum information and computation. Agarwal *et al.* have generated quantum OV (QOV) by coupling two mode squeezed vacuum. Recently OAM is used for quantum cloning, fundamental to develop quantum computer. In this project we will study the various properties of the QOV with application to quantum information and computation. Recently we have studied the Wigner distribution of generalized QOV (GQOV). The statistical properties, entanglement and entropy of (G)QOV state will be computed for different parameter ranges for utilization in quantum computation and quantum information theory. The transformation of (G)QOV through different optical elements will be studied. The propagation of (G)QOV will also be studied through linear and nonlinear media without and with losses.

192. Key words (maximum 6): Quantum, Optical Vortex, Information, Computation.

200. Technical details

210. Introduction (under the following heads)

211. Origin of the proposal

Due to the helical wave front, their spatial structure and associated orbital angular momentum (OAM), optical vortex (OV) beams find a variety of applications in the field of optical manipulation [D.G. Grier, Nature **424**, 810 (2003)], optical communication [G. Gibson, et al., Opt. Exp. **12**, 5448 (2004)], quantum information and computation [A. Mair, et al., Nature **412**, 313 (2001)]. However, most of the work relating to optical vortex deals with classical vortex that involves classical electromagnetic field. It's rare to find literature that takes into account vortex formed by quantized radiation field. Agarwal *et al.* have generated quantum optical vortex (QOV) by coupling two mode squeezed vacuum [G. S. Agarwal, R. R. Puri, and R. P. Singh, Phys. Rev. **A56**, 4207 (1997)], and also shown that a two mode squeezed state under the linear transformation belonging to the SU(2) group may lead to a circular vortex state under special conditions [G. S. Agarwal and J. Banerji, J. Phys. **A39**, 11503 (2006)]. Recently we have studied QOV through Wigner distribution, which is real, nonsingular, yields correct quantum-mechanical operator averages in terms of phase-space integrals, and possesses positive definite marginal distributions [M. Hillery et.al., Phys. Rep. **106**, 121(1984); H.-W. Lee, Phys. Rep. **259**, 147 (1995); W. P. Schleich, *Quantum Optics in Phase Space*, Wiley-VCH, Berlin, ch. 3 (2001)]. The Wigner distribution was used to study generalized case of quantum optical vortex (GQOV), which may be elliptical also, along with circular as a special case, produced from two mode squeezed vacuum [A. Bandyopadhyay and R. P. Singh, Opt. Comn. (2010, doi:10.1016/j.optcom.2010.08.051)]. The Optical Vortices come in the **Sub-area (ii)** of the **thrust areas** of **DST** in **Physical sciences**: ***LASERS, OPTICS, ATOMIC & MOLECULAR PHYSICS, B. Quantum Optics and Basic Laser Physics.*** The next five year plan will be put in the next budget, prompting the proposal to be submitted before that.

212. Definition of the problem:

The entanglement and entropy of generalized quantum optical vortex (GQOV) state will be computed for different parameter ranges for utilization in quantum computation and quantum information. The statistical properties of the GQOV, such as variance and uncertainty will be studied. The effect of different optical elements like beam splitter, mirror and Dove prism [A. K. Jha, G. S. Agarwal and R. W. Boyd, arXiv:1011.2833] on the(G)QOV and their application in quantum circuitry will be studied. Further, the propagation or time evolution of GQOV will also be studied. All these studies will be repeated with losses by standard, but not so trivial master equations [L. Mandel, E. Wolf, *Optical Coherence and Quantum Optics*, Cambridge Univ. Press (1995)], and by a specific treatment of photon–phonon interaction [S.A. Ramakrishna, A. Bandyopadhyay, J. Rai, Opt. Exp. **2**, 29 (1998)] in the medium. The lossy coupling interaction can also be modeled through a three level atom in the Λ configuration [G.S. Agarwal, R.R. Puri, R.P. Singh, Phys. Rev. **A56**, 4207 (1997), A. Bandyopadhyay, J. Rai, Opt. Commun. **140**, 41 (1997)].

213. Objective:

Studying various properties of vortices formed by quantized radiation field, as described in 212, with application to quantum information, circuitry and computation.

220. Review of status of Research and Development in the subject:

221. International status:

Circular optical vortex (OV) beams with helical wave front can be produced in a controlled manner using methods such as computer-generated hologram (CGH), cylindrical lens mode converter, and spiral phase plate [L. Allen et.al., *Progress in Optics*, *Vol.* ***39***, ed. E. Wolf, North-Holland (Amsterdam), 291 (1999); A. T. O'Neil et.al., Phys. Rev. Lett. **88**, 053601(2002); J. Leach et.al., Phys. Rev. Lett. **88**, 257901 (2002).]. However, Quantum vortices are less studied in radiation fields [G. S. Agarwal, R. R. Puri, and R. P. Singh, Phys. Rev. **A56**, 4207 (1997); G. S. Agarwal and J. Banerji, J. Phys. **A39**, 11503 (2006), A. K. Jha, G. S. Agarwal and R. W. Boyd, arXiv:1011.2833]. Recently the OAM has been used for quantum cloning [E. Nagali et.al., Nature Photonics **3**, 720 (2009)], which is fundamental in quantum information in quantum circuitry for development of optical quantum computer.

222. National status:

Optical Vortices come in the **Sub-area (ii)** of the **thrust areas** of **DST** in **Physical sciences**: ***LASERS, OPTICS, ATOMIC & MOLECULAR PHYSICS, B. Quantum Optics and Basic Laser Physics.*** The only studies of quantum optical vortices in literature are by Agarwal et.al. **[**G. S. Agarwal, R. R. Puri, and R. P. Singh, Phys. Rev. **A56**, 4207 (1997); G. S. Agarwal and J. Banerji, J. Phys. **A39**, 11503 (2006)] and the PI, in collaboration with the Quantum Optics and Quantum Information group at Physical Research Laboratory, Ahmedabad [A. Bandyopadhyay and R. P. Singh, Opt. Comn. (2010, doi:10.1016/j.optcom.2010.08.051)].

223. Importance of the proposed project in the context of current status:

Both the optical vortex and quantum computation are very much contemporary topics internationally with over a couple of decades' research work forming the background with immense scope for future technological applications. Optical Vortices come in the **Sub-area (ii)** of the **thrust areas** of **DST** in **Physical sciences**: ***LASERS, OPTICS, ATOMIC & MOLECULAR PHYSICS, B. Quantum Optics and Basic Laser Physics.*** The generalized quantum optical vortex will be studied initially for understanding the underlying fundamental quantum (non-classical) physical properties. Further, the findings will be utilized for quantum information theory and quantum computation.

224. Review of expertise available with proposed investigating group/institution in the subject of the project:

The PI has recently studied the Wigner function of the generalized quantum optical vortex (GQOV) [A. Bandyopadhyay and R. P. Singh, Opt. Commn. (2010, doi:10.1016/ j.optcom.2010.08.051)] in collaboration with Quantum Optics and Quantum Information group at Physical Research Laboratory, Ahmedabad. The PI has previously studied GQOV [A. Bandyopadhyay, International Conference on Squeezed States and Uncertainty Relation VI, Napoli, Italy, (May 24-29, 1999); A. Bandyopadhyay, International Conference for Young Scientists on Laser Physics (LO-YS'2000, St. Petersburg, Russia), p82 (2000)]. He has long experience in working in the field of quantum optics, especially in two mode states [A. Bandyopadhyay, National Laser Symposium (PRL, Ahmedabad, India), p343 (1997); A. Bandyopadhyay and J. Rai, Opt. Commun. 140, 41 (1997); A. Bandyopadhyay, *Ph.D. Thesis*, IIT, Kanpur (1996); A. Bandyopadhyay and J. Rai, in *QELS '96: Summaries of papers presented at the Quantum Electronics and Laser Science Conference*, June 2-7, 1996, Optical Society of America**,** p191 (1996); A. Bandyopadhyay and J. Rai, Phys. Rev., A51, 1597 (1995); A. Bandyopadhyay and J. Rai, in *Advanced Laser spectroscopy and Applications*, ed. H. D. Bist et al., Allied Publishers, ND, 255 (1995)]. He has published on the losses in the medium [S. Anantha Ramakrishna, A. Bandyopadhyay and J. Rai, Opt. Exp., 2, 29 (1998); S.

Anantha Ramakrishna, A. Bandyopadhyay and J. Rai, in *Advanced Laser spectroscopy and Applications*, ed. H. D. Bist et al., Allied Publishers, ND, 257 (1995**)**]. The work will be carried out in collaboration with the Quantum Optics & Quantum Information group of Theoretical Physics Division of Physical Research Laboratory, Ahmedabad, who have been studying classical and quantum optical vortex for more than a decade. They are also implementing their theoretical findings in experiments.

225. Patent details (domestic and international) NA

230. Work plan:

The entanglement and entropy of generalized quantum optical vortex (GQOV) state will be computed for different parameter range with a view to utilize this knowledge in quantum computation and quantum information theory. The statistical properties of the GQOV, such as variances and uncertainty will be studied. The effect of different optical elements like beam splitter, mirror and Dove prism [A. K. Jha, G. S. Agarwal and R. W. Boyd, arXiv:1011.2833] on the(G)QOV and their application in quantum circuitry will be studied. Further, the propagation or time evolution of GQOV will be studied. All these studies will be repeated with losses by standard, but not so trivial master equations [L. Mandel, E. Wolf, *Optical Coherence and Quantum Optics*, Cambridge Univ. Press (1995)], or by a specific treatment of photon–phonon interaction [S.A. Ramakrishna, A. Bandyopadhyay, J. Rai, Opt. Exp. **2**, 29 (1998)] in the medium. The lossy interaction with the medium will also be modeled through a three level atom in the Λ configuration [G.S. Agarwal, R.R. Puri, R.P. Singh, Phys. Rev. **A56**, 4207 (1997), A. Bandyopadhyay, J. Rai, Opt. Commun. **140**, 41 (1997)] for the present situation.

231. Methodology:

From the knowledge of the four dimensional Wigner distribution, other properties of the state, such as averages, variances and uncertainties, entropy and entanglement can be calculated. Then the transformation through optical elements and propagation will be computed in free space and in medium with losses. The computations will be done using MATHEMETICA (to be purchased)

232. Organization of work elements:

First the entanglement and entropy would be studied for the generalized quantum optical vortices. In the next step this knowledge would be utilized for application in quantum circuitry. To investigate how the entanglement and the information entropy would be affected when a GQOV propagates in a medium without and with loss would be our third and final step.

233. Time schedule of activities giving milestones (also append the bar diagram and mark it as Section 410) : We plan to complete the project in three years with schedule as below:

Uncertainty, Entanglement and Entropy:	100% in Year I
Properties under Transformation and Propagation of GQOV:	100% in Year II
Properties under lossy propagation:	100% in Year III

234. Suggested plan of action for utilization of research outcome expected from the project.

The research outcome from the project would be utilized to work further in the field of quantum information and quantum computation. The theoretical results of the research would be used as a guide to do the experiments in the laboratory of Quantum Optics and Quantum Information group at Physical Research Laboratory, Ahmedabad.

(300) BUDGET ESTIMATES: SUMMARY

Item		BUDGET			Total (₹)
		1st Year	2nd Year	3rd Year	
A.	Recurring				
	1.Salaries/wages	245,800	245,800	273,400	7,65,000
	2. Consumables	40,000	5,000	5,000	50,000
	3. Travel	30,000	30,000	30,000	90,000
	4. Other costs/Contingencies	15,000	15,000	15,000	45,000
B.	Equipment	150,000			150,000
	Grand total (A+B) Total FEC*	470,800	295,800	323,400	11,00,000

*FEC- Foreign Exchange Component. Foreign Exchange component (in US$) equivalent of rupee amount at the prevailing rates may be furnished.

N.B. Entries here should match with those given in section 310 to 350; justification for each item is to be given in Section following it that is section 311, 321, 331, 341 and 351.

310. BUDGET FOR SALARIES/WAGES

Designation & number of persons	Monthly Emoluments	BUDGET			Total (m.m.) (₹)
		1st Year (m.m.*)	2nd Year (m.m.)	3rd Year (m.m.)	
JRF	16,000+HRA(15%)	(12) 220,800	(12) 220,800		(24) 441,600
SRF	18,000+HRA(15%)			(12) 248,400	(12) 248,400
Accounts officer	25,000	(1)25,000	(1)25,000	(1)25,000	(3)75,000
Total		245,800	245,800	273,400	765,000

*m.m.:man months to be given within brackets before the budget amount

311. Justification for the manpower requirement.

The JRF, and subsequently SRF, will assist in research, as well as smooth functioning of the project. The accountant will work on the financial matters once annually.

320. BUDGET FOR CONSUMABLE MATERIALS

Item		BUDGET			Total (₹)
		1st Year	2nd Year	3rd Year	
	Q*	1	1	1	
Printer Cartridge	B**		5,000	5,000	10,000
MATHEMATICA (single user)	F***	$770+15.3%Tax			40,000
Total	B		5,000	5,000	10,000
	F				40,000

*Q: Quantity or number, ** Budget, ***F: Foreign Exchange Component in US$

321. Justification for costly consumable (if not provided for in Section 231 i.e. Methodology): MATHEMATICA for computation. Other not costly.

330. BUDGET FOR TRAVEL

Travel (Only inland travel)	BUDGET (₹)			
	1st Year	2nd Year	3rd Year	Total
	30,000	30,000	30,000	90,000

331. Justification for intensive travel, if any.
Meeting of PI with his collaborator at PRL, Ahmedabad for discussion, and attend National Meetings to present research findings.

340. BUDGET FOR OTHER COSTS/CONTINGENCIES

Other costs/ Contingency costs	BUDGET (₹)			
	1st Year	2nd Year	3rd Year	Total
	15,000	15,000	15,000	45,000

341. Justification for specific costs under other costs, if any. Contingency

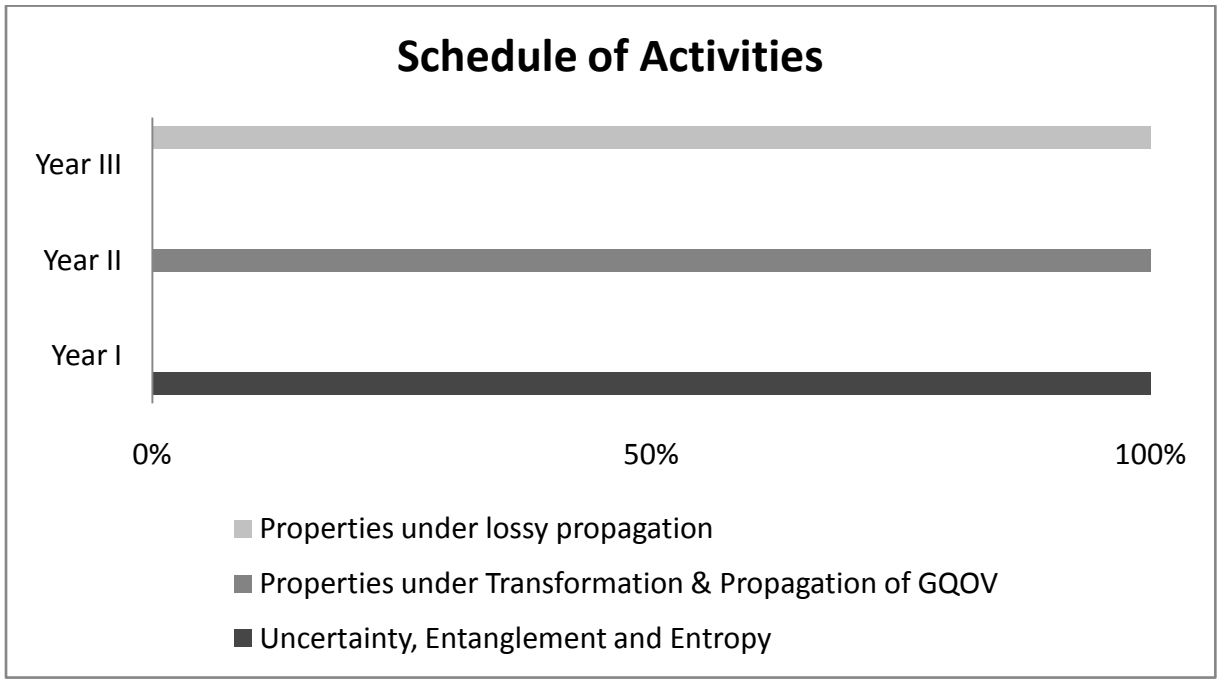
350. BUDGET FOR EQUIPMENT

Sl. No.	Generic name of the Equipment along with make & model	Imported/ Indigenous	Estimated Costs (in Foreign Currency also)*	Spare time for other users (in %)
1.	Laptop (HP Envy 14-1000 Notebook)	Indigenous	₹ 67,000	NA
2.	**Laser Printer (**HP LaserJet Pro M1130 Multifunction Printer**)**	Indigenous	₹ 16,500	
3.	AC (VERTIS PREMIUM SAC 1.5T)	Indigenous	₹ 26,500	
4.	Furniture (1 Almirah, 4 chairs, 2 tables)	Indigenous	₹ 40,000	
Total:			₹ 150,000	

* includes transport, insurance and installation charges.

351. Justification for the proposed equipment. Computation, Printing/copying, Cooling of room, furniture.

410. Time Schedule of Activities through BAR Diagram



420. List of facilities being extended by parent institution(s) for the project implementation.

A) Infrastructural Facilities:

Sr. No.	Infrastructural Facility	Yes/No/ Not required Full or sharing basis
1.	Workshop Facility	NR
2.	Water & Electricity	Y
3.	Laboratory Space/ Furniture	Y/N
4.	Power Generator	Y
5.	AC Room or AC	N
6.	Telecommunication including e-mail & fax	Y
7.	Transportation	Y
8.	Administrative/ Secretarial support	N
9.	Information facilities like Internet/ Library	Y
10.	Computational facilities	Y
11.	Animal/ Glass House	NR
12.	Any other special facility being provided	N

B. Equipment available with the Institute/ Group/ Department/ Other Institutes for the project:

NA

Equipment available with	Generic Name of Equipment	Model, Make & year of purchase	Remarks including accessories available and current usage of equipment
PI & his group			
PI's Department			
Other Inst in the region			

430. Detailed Bio-data of the Investigator(s)/Co-Investigator(s) including Name, Address, Date of Birth, Institution's Address etc.; Academic Qualifications (University/College from where attained, year of passing, class, Thesis title etc.), Publications list (Title of paper, authors, Journal details, pages, year etc.), Patent list, if any, List of Projects implemented

Bio-data (PI)

Name : **ABIR BANDYOPADHYAY**

Date of Birth : December 29, 1965

Addresses: Postal : **Hooghly Engg. and Tech. College, Pipulpati, Hooghly 712 103.**
Email : abir@hetc.ac.in Mob. : (91) 98316 26423
URL : http://www.hetc.ac.in/abir.html

Present Position : **Senior Lecturer**

Academic Qualification:

Year	Degree	Institute/University	Class	Remarks
1998	Ph.D.*	I. I. T., Kanpur	I(CPI:7.25)	Sub. : Dec. '96; Def. : Nov. '97
1988	M.Sc	Jadavpur University	II (57.9%)	Exam in 1989
1986	B.Sc.	Jadavpur University	II (56%)	

*Dissertation: ***Coherent and Squeezed Angular Momentum States in Schwinger Representation with Applications to Quantum Optics***

Post Doctoral Research:

Organization	Address	Position	From	To
Jawaharlal Nehru Centre for Advanced Scientific Research (JNC-ASR)	Bangalore 560 064	Research Associate	18.08.99	31.08.01
Centre for Theoretical Studies (CTS), Indian Institute of Science (IISc)	Bangalore 560 080	Research Associate	18.08.98	17.08.99
Physical Research Laboratory (PRL)	Ahmedabad 380 009	Postdoctoral Fellow	16.12.96	15.06.98

Refereed Publications : 14

Journal : 5 (International) + 1 (National)
In Book : 1 (International) + 2 (National)
Conf. Proceedings : 4 (International) + 1 (National)

Other Achievements:

1. ***Associate*** for four months by PRL, Ahmedabad 380 009, to research on Quantum Optical Vortex, during 2010-12**.**
2. ***Summer Research Fellow 2008,*** jointly by **IASc**, **Bangalore**, **INSA**, **ND** and **NASI**, **Allahabad**, to work under the guidance of **Dr. Bikash Sinha**, Director, VECC & SINP, Kolkata.
3. ***Category A Speaker*** in Theoretical Physics Seminar Circuit (**TPSC**) by S.N. Bose National Centre for Basic Sciences, Kolkata, for years 1995-96, 1999-2000, and 2000-01.
4. Qualified **NET, 1989** and **GATE 1990**.
5. **Government of India *Merit cum Means Scholar,*** Ministry of Education and Social Welfare, 1977, for complete (Tuition, Books, Residential and Clothing) expenses at specific institutions up to High School level (availed during 1978-82).
6. ***Merit cum Means Stipend holder*** (50%) by RKM Vidyapith, Purulia for Tuition and Residential expenses during 1975-77.

References:

1. Prof. Jagdish Rai Luthra
   Departamento de Física, Universidad de los Andes, A. A. 4976, Bogota, **COLOMBIA**.
   Email: jluthra@uniandes.edu.co
2. Prof. Girish Sharan Agarwal, **Noble Foundation Chair & Regent Professor**
   Department of Physics, 145-Physical Sciences, Oklahoma State University, Stillwater, Oklahoma-74078, **USA**.
   Email: girish.agarwal@okstate.edu
3. Prof. N. Kumar, **Chairman, IISER, Pune & Ex-director, RRI, Bangalore**
   Raman Research Institute, Sadashivnagar, Bangalore 560 064, **INDIA**.
   Email: nkumar@rri.res.in
4. Prof. V. Ravishankar
   Dept. Of Physics, IIT, Kanpur 208 016, **INDIA**
   Email: vravi@iitk.ac.in

Publications:

1. *Wigner distribution of elliptical quantum optical vortex*, **Abir Bandyopadhyay** and R. P. Singh, **Optics Communications** (**2010, doi:10.1016/j.optcom.2010.08.051**); **arXiv:1007.0697.**
2. *Nuclear matter equation of state, incompressibility and proton radioactivity***,** **Abir Bandyopadhyay** and D.N. Basu, **Acta Physica Polonica, B 40, 165 (2009).**
3. *A dissipative quantum mechanical beam-splitter***,** S. Anantha Ramakrishna, **Abir Bandyopadhyay** and Jagdish Rai, **Optics Express, 2, 29 (1998).**
4. *Transfer of non-classical properties in dual channel directional coupler***, Abir Bandyopadhyay** and Jagdish Rai, **Optics Communications, 140, 41 (1997).**
5. *Uncertainties of Schwinger angular-momentum operators for squeezed radiation in interferometers***, Abir Bandyopadhyay** and Jagdish Rai, **Physical Review, A 51, 1597 (1995).**
6. *Transfer of non-classical properties in dual channel optical coupler***, Abir Bandyopadhyay** and Jagdish Rai, In **QELS '96**: Summaries of papers presented at the **Quantum Electronics and Laser Science Conference, June 2-7, 1996**, Optical Society of America (**OSA), p191 (1996).**
7. *Angular constraints in cold d-t fusion catalyzed by negative muons***,** Lali Chatterjee and **Abir Bandyopadhyay, Ind. J. Phys., 64A, 160 (1990).**
8. *Optical interferometry with squeezed radiation***, Abir Bandyopadhyay** and Jagdish Rai, In **Advanced Laser spectroscopy and Applications**, ed. H. D. Bist et al., **Allied Publishers, ND, 255 (1995).**
9. *Quantum mechanical reflection with losses***,** S. Anantha Ramakrishna, **Abir Bandyopadhyay** and Jagdish Rai, In **Advanced Laser spectroscopy and Applications**, ed. H. D. Bist et al., **Allied Publishers, ND, 257 (1995).**
10. *Propagation of elliptical vortex with circular hole embedded in an elliptical Gaussian background laser beam***, Abir Bandyopadhyay,** International Conference for Young Scientists on Laser Physics **(LO-YS'2000, St. Petersburg, Russia)**, p82 (2000).
11. *Quantum statistical properties of generalized optical vortex with squeezed coherent states***, Abir Bandyopadhyay,** International Conference on Squeezed States and Uncertainty Relation **(ICSSUR VI, Napoli, Italy)**, (May 24-29, 1999).
12. *Squeezing in molecular vibrational excitations***,** Arnab Majumdar, Kingshuk Ghosh, **Abir Bandyopadhyay**, Mahendra K. Verma and Jagdish Rai, International Conference on Quantum Optics and Laser Physics **(ICQOLP, Hong Kong)**, ed. S.-Y. Zhu, p64 (1997).
13. *Squeezing and amplification without inversion in the interaction of coherent radiation and two-level atoms***, Abir Bandyopadhyay** and Jagdish Rai, International Symposium on Atomic Coherence and Inversion-less Amplification **(ISAMP,** Changchun, **China)**, ed. J. Y. Gao and S.-Y. Zhu, p104 (1995); arXiv: atom-ph/9509005.
14. *Coherent and squeezed angular-momentum states in Schwinger representation with applications to Quantum Optics*, **Abir Bandyopadhyay,** National Laser Symposium **(PRL, Ahmedabad, India)**, p343 (1997).

450. Details of Research Projects being implemented/ completed/ submitted by the Investigator(s)/Co-Investigators including Investigator(s) NA

Name & Institute
Project Title
Project Status:
Completed-duration, period (from.... to.....), funding agency and total cost
On-going-duration, date of start, funding agency and total cost
proposed-duration, funding agency where submitted and total cost
Summary of the project
Major Results/ Highlights of the project including achievement (publications, patents etc.), for *completed projects*
Up-to date Technical progress report for *on-going projects.*

500.Any other relevant matter.