Posudek práce

předložené na Matematicko-fyzikální fakultě
Univerzity Karlovy

❑ posudek vedoucího ■ posudek oponenta
■ bakalářské práce ❑ diplomové práce

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Název práce: Thermodynamics of black holes. Entropy and information.
Studijní program a obor: Obecná fyzika
Rok odevzdání: 2018

Jméno a tituly vedoucího/oponenta: Mgr. Martin Scholtz, Ph.D.
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Odborná úroveň práce:
■ vynikající ❑ velmi dobrá ❑ průměrná ❑ podprůměrná ❑ nevyhovující

Věcné chyby:
❑ téměř žádné ■ vzhledem k rozsahu přiměřený počet ❑ méně podstatné četné ❑ závažné

Výsledky:
❑ originální ❑ původní i převzaté ■ netriviální kompilace ❑ citované z literatury ❑ opsané

Rozsah práce:
❑ veliký ■ standardní ❑ dostatečný ❑ nedostatečný

Grafická, jazyková a formální úroveň:
■ vynikající ❑ velmi dobrá ❑ průměrná ❑ podprůměrná ❑ nevyhovující

Tiskové chyby:
■ téměř žádné ❑ vzhledem k rozsahu a tématu přiměřený počet ❑ četné

Celková úroveň práce:
❑ vynikající ■ velmi dobrá ❑ průměrná ❑ podprůměrná ❑ nevyhovující

Slovní vyjádření, komentáře a připomínky vedoucího/oponenta:

The subject of the thesis is black hole thermodynamics (including quantum effects) and its relation to information and entropy. In the first part, the author gives comprehensive review of the 4 laws of black hole mechanics and presents derivations of pivotal results. I appreciate especially the derivation of the 1st law of thermodynamics following the approach of Bardeen-Carter-Hawking which is very laborious and involved. Then, derivation of the Hawking effect in the WKB approximation is sketched.

The second part of the thesis is devoted to the notion of information, entropy and connections between them. After introducing the Shannon entropy, the author proceeds to the description of mixed states by density matrices and associated von Neumann entropies. Finally, these concepts are related to the black hole entropy and the essence of the black hole information paradox is briefly discussed.

The thesis is a reasonable review of a very wide and difficult are covering topics from classical differential geometry and general relativity, quantum field theory and information theory. Although the thesis does not address all issues very deeply, which is understandable since it is a bachelor thesis, and the number of topics certainly counterbalances the lack of details. Moreover, the author has shown that he is able to work with the literature, extract important information, provide missing arguments and repeat the calculations.

Regarding the difficulty and the breadth of the subject, I think that the thesis is very well-written (including the level of English), contains non-trivial information and appropriate list of references. Although the work does not include new, original results, it can serve as an excellent introductory text to black hole thermodynamics. For these reasons, **I recommend to accept** this bachelor thesis.

Případné otázky při obhajobě a náměty do diskuze:

Section 1.2.1. - The area increase theorem. I don't like this proof because it does not essentially prove anything and the real proof is hidden in the conclusion "the expansion blows up at some point, which is unphysical and violates some known black hole properties". My objections:

- The proof, as it stands, does not invoke any properties of black holes and holds for any null hypersurface.
- It is not clear that the pathological behavior in the case $\theta_0 < 0$ is physical and not the consequence of the gauge. For example, appropriate redefinition of the parameter lambda could move the singular point of the congruence to infinity. Why is this possibility excluded?
- The actual proof requires global structure of the spacetime. The argument, roughly, is that if the horizon has negative expansion, *any* null geodesic starting sufficiently close to the horizon will intersect the horizon in a finite "time". This is incompatible with asymptotic flatness, i.e. with the fact that (off the horizon) there must exist null geodesics that can escape to null infinity.

Section 1.6. - Hawking radiation and black hole temperature.

- What is the advantage of Gullstrand-Painlevé coordinates? (compared to, e.g. Eddington-Finkelstein coordinates)
- What is the actual error in using WKB method compared to non-perturbative treatment? What plays the role of the WKB scaling parameter in this analysis?
- Could the author make some link to standard, field picture? Where does the metric enter? Only the geodesic equation?
- In the field picture, one has to select specific observers and identify vacuum states associated with such observers. Only then the notion of particles/antiparticles makes sense. How does WKB approximation deals with these problems?

Práci
■ doporučuji
❑ nedoporučuji
uznat jako diplomovou/bakalářskou.

Navrhuji hodnocení stupněm:
❑ výborně ❑ velmi dobře ❑ dobře ❑ neprospěl/a

Místo, datum a podpis vedoucího/oponenta:

V Praze, 17. června 2018