Q AL FY NG EXAM N GEOME RY AND OPOLOGY MMER 11

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(1) **Let S be a closed non-orientable surface of genus g.**

- **(a)** **What is $H_i(S; \mathbb{Z}_2)$? (answer only)**
- **(b)** **Find out the maximal number of disjoint orientation reversing simple closed curves in S. (Justify your answer)**

(2) **Let X be a path-connected space and $\widetilde{X}$ a universal covering space of X. Prove that if $\widetilde{X}$ is compact, then $\pi_1(X)$ is a finite group.**

(3) **Let M be a compact, connected, orientable n-manifold, where n is odd.**
(You may assume, if you like, that M is triangulated.)

- **(a)** **Show that if $\partial M = \emptyset$, then $\chi(M) = 0$.**
- **(b)** **Show that if $\partial M \neq \emptyset$, then $\chi(M) = \frac{1}{2}\chi(\partial M)$.**

(4) **Let M be a closed 3-manifold. Suppose M is a homology sphere, i.e., M has the same $\mathbb{Z}$-coefficient homology groups as S^3, in other words, $H_n(M; \mathbb{Z}) = H_n(S^3; \mathbb{Z})$ for all n. Let k be a knot in M (i.e., k is a closed 1-dimensional submanifold of M, in other words, k is an embedded closed curve S^1 in M). Compute $H_n(M - k; \mathbb{Z})$ for all n, where $M - k$ is the complement of k.**

GT Qual 2011 Part II

Show All Relevant Work!

1) The image of the map $X : \mathbb{R}^2 \to \mathbb{R}^3$ given by

$$X(\ ;\ ) = ((2 + \cos(\ ))\cos(\ ), (2 + \cos(\ ))\sin(\ ), \sin(\ ))$$

is the torus obtained by revolving the circle $(y - 2)^2 + z^2 = 1$ in the yz plane about the z axis. Consider the map $F : \mathbb{R}^3 \to \mathbb{R}^2$ given by $F(x, y, z) = (x, z)$ and let $f = (F$ restricted to the torus).

a) Compute the Jacobian of the map $f \circ X$. (Note that the map X descends to an embedding of $S^1 \times S^1$ into $\mathbb{R}^3$ but we don't need to obsess over the details of this.)

b) Find all regular values of f.

c) Find all level sets of f that are *not* smooth manifolds (closed embedded submanifolds).

2a) Write down the deRham homomorphism for a smooth manifold M; explain briefly why this definition is independent of the (two) choices made.

b) State the deRham Theorem for a smooth manifold M.

c) A crucial step in the proof of the deRham Theorem is: If M is covered by 2 open sets U and V, both of which and their intersection satisfy the deRham theorem, then $M = U \cup V$ satisfies the deRham theorem. Briefly explain how this crucial step is proven.

3a) If $\ $ is a differential form, then must it be true that $\ \wedge\ = 0$? If yes, then explain your reasoning. If no, then provide a counterexample.

b) If $\ $ and $\ $ are closed differential forms, prove that $\ \wedge\ $ is closed.

c) If, in addition (i.e., continue to assume that $\ $ is closed), $\ $ is exact, prove that $\ \wedge\ $ is exact.

4) The Chern-Simons form for a hyperbolic 3-manifold with the orthonormal framing (E_1, E_2, E_3) is the 3-form

$$Q = \left(\frac{1}{8\pi^2}\right)(\omega_{12} \wedge \omega_{13} \wedge \omega_{23} - \omega_{12} \wedge\ _1 \wedge\ _2 - \omega_{13} \wedge\ _1 \wedge\ _3 - \omega_{23} \wedge\ _2 \wedge\ _3)$$

where $(\ _1,\ _2,\ _3)$ is the dual co-frame to (E_1, E_2, E_3) (note that [Lee] uses $\ $, but here we use $\ $) and the ω_{ij} are the *connection* 1-forms. The connection 1-forms satisfy

$$d\ _1 = -\omega_{12} \wedge\ _2 - \omega_{13} \wedge\ _3$$
$$d\ _2 = +\omega_{12} \wedge\ _1 - \omega_{23} \wedge\ _3$$
$$d\ _3 = +\omega_{13} \wedge\ _1 + \omega_{23} \wedge\ _2$$

a) In $\mathbb{H}^3 = \{(x, y, z) : z > 0\}$ with the Riemannian metric $g = \frac{1}{z^2}dx \otimes dx + \frac{1}{z^2}dy \otimes dy + \frac{1}{z^2}dz \otimes dz$, orthonormalize the framing $(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z})$.

b) Compute the associated dual co-frame $(\ _1,\ _2,\ _3)$.

c) For this orthonormal framing (and dual co-frame), in $(\mathbb{H}^3, g)$, compute the Chern-