

Due at the beginning of class on 8 April 2025

- Your answers should be neatly written and logically organized.
- You may collaborate on solving the problems, but the solutions you turn in should be your own.
- You may use any resource you find online (or elsewhere), but you must cite any resource you use.

Reading: [Mal23, Sections 4.1 and 4.3] and the introduction to [Lew91].

- (1) Define spectrum structure maps for a “fake smash product” $\wedge_{\text{fake}}: \mathcal{S}p \times \mathcal{S}p \rightarrow \mathcal{S}p$ with n -th space

$$(X \wedge_{\text{fake}} Y)_n = X_n \wedge Y_n.$$

Argue that, with your choice of structure maps, $(\mathcal{S}p, \wedge_{\text{fake}}, S)$ is *not* a symmetric monoidal category.

- (2) (a) Let \mathcal{C} be a category that is both additive and symmetric monoidal with product \otimes and unit I . Assume that \otimes preserves coproducts in each variable separately. Prove that the product induces bilinear maps

$$\mathcal{C}(A, B) \times \mathcal{C}(X, Y) \rightarrow \mathcal{C}(A \otimes X, B \otimes Y)$$

- (b) Show that there is no natural transformation in the stable homotopy category $\delta: X \rightarrow X \wedge X$ that agrees with the diagonal on suspension spectra

$$\Sigma^\infty K \xrightarrow{\Sigma^\infty \Delta} \Sigma^\infty (K \wedge K) \cong \Sigma^\infty K \wedge \Sigma^\infty K.$$

Hint: argue by contradiction and apply δ to $S \xrightarrow{2} S$.

- (3) Assume that we are given a closed symmetric monoidal category of spectra $(\widehat{\mathcal{S}p}, \wedge, S)$ such that \wedge preserves colimits and weak equivalences in each variable separately, and for any pointed space K , $\Sigma^\infty K \wedge X \cong K \wedge X$. The right adjoint to $X \wedge -$ is the function spectrum $F(X, -)$. Write $S^n := \Sigma^\infty S^n$.

- (a) Prove that for any integer $n \in \mathbb{Z}$, the smash product $S^n \wedge X$ is stably equivalent to $\Sigma^n X$.
 (b) Prove that for any integer $n \in \mathbb{Z}$, the function spectrum $F(S^n, X)$ is stably equivalent to $\Sigma^{-n} X$.

- (4) Let X be an $H\mathbb{F}_p$ -module spectrum. What does this imply about the homotopy groups of X ? Can you say anything about the homology groups?

REFERENCES

[bip] nLab: biproduct. “<https://ncatlab.org/nlab/show/biproduct>”.

[Lew91] L. Gaunce Lewis, Jr. Is there a convenient category of spectra? *J. Pure Appl. Algebra*, 73(3):233–246, 1991.

[Mal23] Cary Malkiewich. Spectra and stable homotopy theory. http://people.math.binghamton.edu/malkiewich/spectra_book_draft.pdf, October 2023.